Wiley's Remediation Technologies Handbook

MAJOR CONTAMINANT CHEMICALS AND CHEMICAL GROUPS

JAY H. LEHR

CD-ROM INCLUDED

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Major Contaminant Chemicals and Chemical Groups

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CONTENTS

PREFACE

I have personally been involved in environmental remediation projects for half a century and am still going strong. In some regards it was easier decades ago when there were few proven options for the wide variety of chemical contaminants that plagued our waters, soil, and air. Of course, there were also less clear-cut success stories. Today there exists a myriad of proven options successfully implemented by intelligent environmental scientists, consulting firms, and technology providers.

It has thus become difficult to understand the many options and their efficacy under a variety of conditions relating to concentrations, media, confounding conditions, and environmental sensitivity. One always has to wonder if there might not be a better solution. Now one need wonder no longer. This handbook presents the most comprehensive collection of technologies that have proven successful in field conditions since environmental engineering became one of our nation's most important technological professions.

In this handbook you will discover 901 existing innovative and emerging solutions to contaminant problems. Each technique features a carefully worded yet brief summary of the technology written by specialists in the field in collaboration with talented technical editors. Each is accompanied by technical and cost performance reports, source documents, and the vendors that may specialize in the various applications.

Because no one would want to wade through 901 proven technologies to find the right one for his or her problem, we have provided simple paths to the right solutions.

First, we sorted every conceivable chemical of concern into chemical groups in the book's opening index. The available technologies are then listed for each chemical in the appropriate chemical group in the handbook's second index. Each technology is listed by a numeric code along with its title and a company specializing in its use.

The next section lists the 901 technologies in their numeric order with their descriptions, case studies, costs, and references. Throughout the technology section we refer to this database as RIMS, which stands for Remediation Information Management System. This, the largest section of the handbook, is followed by a compilation of references for each technology. They are again listed in numerical order, but the related references are divided into groupings that relate to total costs, technology costs, general studies, and technology descriptions. The complete bibliographic citations for these references can be found on the CD ROM that accompanies this book.

The handbook concludes with a specific chemical index that cross references every included chemical with the group with which it is linked. In short, there are simply no dead ends in this book. No matter where you start, you will find a smooth path to the information you desire.

The information in this book was obtained from every imaginable source within the environmental science and engineering profession. They include virtually every peer-reviewed journal in the field, every government-issued report, the proceedings of every related conference in the past two decades, as well as publications of commercial companies working in this field. Ultimately the providers of every technology were contacted personally for interviews involving their work. Only top-quality services and products survived the search for information and eventual publication in this handbook.

We hope every reader, company, organization, and government agency that utilizes this hard-won compendium of remediation knowledge finds it to be a useful tool in the continuing effort to improve and protect an environment that has been severely stressed by our many industrial advances.

JAY H. LEHR

AR Environmental Services, Inc.
The Heartland Institute

CHEMICALS SORTED BY CHEMICAL GROUPS

Alcohols
Aldehydes
  Aldehydes
  Butyraldehyde
  Formaldehyde
Aldehydes and Ketones
Aldehydes or Ketones with Other Functional Groups
  Aldehydes, Ketones with Other Functional Groups
  Kepone; Chlordecone
Aliphatic Hydrocarbons
Aliphatic Nitriles and Cyanates
  Acetonitrile
  Acrylonitrile
  Aliphatic Nitriles
Aliphatic Nitrosamines
  Aliphatic Nitrosamines
  N-Nitrosodimethylamine (NDMA)
Aliphatic Organophosphorous Compounds
  Aliphatic Organophosphorous Compounds
  Dibutyl Phosphate
  Tributyl Phosphate
Alkanes and Cyclic Alkanes
  Alkanes and Cyclic Alkanes
  Cyclohexane
  Decane, *n*
  Heptanes
  Hexadecane
  Hexanes

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  - Isobutane
  - Methane
  - Methyl Cyclohexane
  - Nonane
  - Octane, iso; Isooctane
  - Pentanes
  - Propane
- Alkenes, Cyclic Alkenes, and Dienes
  - Alkenes, Cyclic Alkenes, and Dienes
  - Ethylene
  - Propylene
- Alkyl Halides
- Alkynes
- Aluminum
- Americium
- Amides
  - Amides
  - Carbofuran
  - Dimethyl Acetamide
- Amines
- Antimony
- Aromatic Amines and Diamines
  - Aniline
  - Aromatic Amines and Diamines
  - Atrazine
  - Benzidine
  - Chloroaniline, 4
  - Chloroaniline(bis) Methylene; Methylene Bis(chloroaniline); MBOCA; Dichlorodiaminodiphenyl Methane
  - Dichlorobenzidine, 3,3
  - Propazine
- Aromatic Nitriles and Cyanates
  - Aromatic Nitriles
  - Toluene Diisocyanate
- Aromatic Nitro Compounds
- Aromatic Nitro Compounds with Other Functional Groups
  - Aromatic Nitro Compounds with Other Functional Groups
  - Pentachloronitrobenzene
- Aromatic Organophosphorous Compounds
  - Aromatic Organophosphorous Compounds
  - Parathion
- Aromatics with Halogenated Side Chain
  - Aromatics with Halogenated Side Chain
  - Benzyl Chloride; Chlorotoluene, Alpha
  - DDT; Trichloro(chlorophenyl,4-bis) Ethane
- Arsenic
- Azo Compounds
  - Azo Compounds
  - Azobenzene
- Azo Compounds, Hydrazine Derivatives

Barium
Benzene and Monosubstituted Benzene Hydrocarbons
  Benzene
  Benzene and Monosubstituted Benzene Hydrocarbons
  Biphenyl
  Cumene; Isopropyl Benzene; Methylethyl Benzene
  Ethylbenzene
  Styrene
  Toluene
Benzene and Substituted Benzene Hydrocarbons
Benzene, Toluene, Ethylbenzene, and Xylene (BTEX)
Beryllium
Bismuth
Bromide Ion
Cadmium
Calcium
Carbon Compounds
  Carbon Compounds
  Carbon Monoxide
Carboxylic Acids
  Acetic Acid
  Acrylic Acid; Propenoic Acid
  Benzoic Acid
  Carboxylic Acids
Carboxylic Acids and Derivatives
Carboxylic Acids with Other Functional Groups
  Carboxylic Acids with Other Functional Groups
  Dichlorophenoxyacetic Acid; 2,4-D
Cesium
Chlorine and Chlorine Compounds
Chlorine Compounds
  Chlorine Compounds
  Chlorine Gas
Chlorine, Ionic Species
  Chlorides
  Chlorine, Ionic Species
  Perchlorates
Chromium
Chromium-Containing Ionic Species
  Chromate Ion, Hexavalent Chromium
Cobalt
Copper
Cyclic Ethers
  Cyclic Ethers
  Dioxane-1,4
  Ethylene Oxide
Dihalogenated and Polyhalogenated Ethers
  Dichloroethyl, 1,1-Ether
  Dichloromethyl, 1,1-Ether; Methyl-dichloro-1,1-ether
  Dieldrin

- Dihalogenated and Polyhalogenated Ethers
- Endrin
- Trichlorophenoxyacetic, 2,4,5 Acid

Dioxin and Related Compounds
- Dioxin and Related Compounds
- HxCDF; Hexachlorodibenzofurans
- TCDD; Tetrachlorodibenzodioxins
- TCDF; Tetrachlorodibenzofurans

Disubstituted and Polysubstituted Benzene Hydrocarbons
- Diethyl Benzene
- Disubstituted and Polysubstituted Benzene Hydrocarbons
- Ethyltoluene
- Indene; Dihydroindene
- Trimethyl Benzene
- Xylenes

Elemental Sulfur

Epoxides

Esters
- Butyl Acrylate; Propenoic Acid, Butyl Ester
- Esters
- Ethyl Acetate
- Ethyl Acrylate
- Ethyl Lactate; Hydroxypropanoic Acid, Ethyl Ester
- Methyl Methacrylate
- Phthalate, Butyl Benzyl; Butyl Benzyl Phthalate
- Phthalate, Dibutyl; Dibutyl Phthalate, *n*
- Phthalate, Diethylhexyl; Diethylhexyl Phthalate
- Phthalate, Dimethyl; Dimethyl Phthalate
- Phthalate, Dioctyl; Di-*n*-octyl Phthalate
- Vinyl Acetate

Ethers

Fluoride Ion

Glycols
- Ethylene Glycol
- Glycols
- Propylene Glycol
- Propylene Glycol Monoethyl Ether Acetate (PGMEA)

Glycols, Epoxides

Gold

Halogenated Aromatic Compounds

Halogenated Cresols

Halogenated Ethers and Epoxides

Halogenated Phenolic Compounds

Halophenols
- Chlorophenol
- Dichlorophenol
- Halophenols
- Pentachlorophenol; PCP
- Tetrachlorophenol
- Trichlorophenol

Heterocyclic Nitrogen Compounds

Heterocyclic Oxygen Compounds

Heterocyclic Oxygen Compounds with Three or More Rings
- Dibenzofuran
- Oxygen Heterocycles with Three or More Rings

Hydrazine Derivatives
- Dimethylhydrazine, *N*,*N*; Unsymmetrical Dimethylhydrazine
- Hydrazine Derivatives
- Methylhydrazine; Monomethylhydrazine

Iodine

Ionic Species Containing Iron
- Ferrocyanide Ion

Ions Containing Phosphorus
- Phosphate

Ions Containing Sulfur
- Sulfate Ion
- Sulfide Ion

Ions with Nitrogen
- Ammonium Ion; NH_4^+
- Cyanide (CN^-)
- Hydrazine
- Nitrate (NO_3^-)

Iron

Ketones
- Acetone
- Butanone; MEK; Methyl Ethyl Ketone
- Cyclohexanone
- Isophorone
- Isopropylacetone; Methyl Isobutyl Ketone; Hexone; 4-Methyl-2-pentanone
- Ketones

Lanthanides

Lead

Lead Compounds
- Lead Compounds
- Tetraethyl Lead

Lithium

Magnesium

Manganese

Mercury

Molybdenum

Monohydric Phenols
- Monohydric Phenols
- Phenol
- Phenol, Dimethyl; Xylenols
- Phenol, Methyl; Cresols; Methyl Phenol

Nickel

Nitrogen Compounds
- Ammonia
- Nitrogen Trifluoride

Nitrophenolic Compounds

Nitrophenols
- Nitrophenol, 4; Nitrophenol, *p*
- Nitrophenols
- Picric Acid; Trinitrophenol

Nitrosamines

Noncyclic Aliphatic or Aromatic Ethers
  Diethyl Ether
  Methyl *tert*-Butyl Ether; MTBE; Methyl Tertiary Butyl Ether
  Noncyclic Aliphatic or Aromatic Ethers
  Tetrahydrofuran
Organophosphonates
  Diisopropyl Methyl Phosphonate; DIMP
  Organophosphonates
Organophosphorus Compounds
Organosulfur Compounds with Other Functional Groups
  Endosulfan
  Organosulfur Compounds with Other Functional Groups
Other Nitrophenols
  Dinoseb; *sec*-Butyl Dinitrophenol; Dinitrophenol, 4,6-*sec*-Butyl
  Other Nitrophenols
Pesticides
  Pesticides/Herbicides
Phenols
Platinum
Plutonium
Polycyclic Aromatic Hydrocarbons with More Than Five Fused Rings
  Benzo(*g*,*h*,*i*)perylene
  Polycyclic Aromatic Hydrocarbons with More Than Five Fused Rings
Polycyclic Aromatic Hydrocarbons, Four-Ring Compounds
  Benzo(*a*)anthracene
  Chrysene
  Polycyclic Aromatic Hydrocarbons with Four Fused Rings
  Pyrene
Polycyclic Aromatic Hydrocarbons, Two- or Three-Ring Compounds
  Acenaphthene
  Acenaphthylene
  Anthracene
  Methylnaphthalene
  Naphthalene
  Phenanthrene
  Polycyclic Aromatic Hydrocarbons with Two or Three Fused Rings
Polycyclic Aromatic Hydrocarbons; PAH; PNA; POM
Polycyclic Hydrocarbons, Nonalternant Compounds with Four Fused Rings
  Fluoranthene
  Four-Ring Fused Nonalternant Hydrocarbons
Polycyclic Hydrocarbons, Nonalternant Compounds with Five Fused Rings
  Benzo(*b*)fluoranthene
  Benzo(*k*)fluoranthene
  Polycyclic Hydrocarbons, Nonalternant Compounds with Five Fused Rings
Polycyclic Hydrocarbons, Nonalternant Compounds with Fused Rings
Polycyclic Hydrocarbons, Nonalternant Compounds with More Than Five Fused Rings
  Indeno(1,2,3-*cd*)pyrene
  Polycyclic Hydrocarbons, Nonalternant Compounds with More Than Five Fused Rings
Polycyclic Hydrocarbons, Nonalternant Compounds with Two or Three Fused Rings
  Fluorene
  Indene
  Polycyclic Hydrocarbons, Nonalternant Compounds with Two or Three Fused Rings

Polycyclic Aromatic Hydrocarbons, Five-Ring Compounds
  Benzo(*a*)pyrene
  Dibenzo(*a*,*h*)anthracene
  Polycyclic Aromatic Hydrocarbons, Four-Ring Compounds
Potassium
Primary Alcohols
  Benzyl Alcohol
  Butanol, *n*
  Ethanol
  Methanol
  Primary Alcohols
Primary Aliphatic Amines and Diamines
  Hexylamine
  Monomethylamine
  Primary Aliphatic Amines
Pyridine and Substituted Pyridines
  Paraquat
  Pentachloropyridine
  Pyridine
  Pyridine and Substituted Pyridines
Pyrrole and Fused-Ring Derivatives of Pyrrole
  Captan
  Pyrrole and Fused-Ring Derivatives of Pyrrole
Radionuclides
Radium
Ring-Substituted Aromatics
  Chlorobenzene; Monochlorobenzene
  Chlorotoluene, 2
  DDD; Dichloro(chlorophenyl)-bis Ethane
  DDE; Dichlorodiphenyldichloroethylene
  Dichlorobenzene, 1,2
  Dichlorobenzene, 1,3
  Dichlorobenzene, 1,4
  Hexachlorobenzene
  Polychlorinated Benzenes
  Polychlorinated Biphenyls; PCBs; Aroclor
  Ring-Substituted Aromatics
  Tetrachlorobenzene
  Trichlorobenzene, 1,2,4
Saturated Alkyl Halides
  Bromodichloromethane
  Bromoform; Tribromomethane
  Butyl Chloride; Chlorobutane
  Carbon Tetrachloride
  Carbon Tetrafluoride
  Chloroform; Trichloromethane
  Chloromethane; Methyl Chloride
  Dibromochloromethane
  Dibromoethane, 1,2; Ethylene Dibromide
  Dibromomethane
  Dichlorodifluoromethane; Freon 12
  Dichloroethane, 1,1

- Dichloroethane, 1,2; DCA
- Dichloropropane, 1,2
- Dichlorotrifluoroethane; HCFC-1,2,3
- Ethyl Chloride; Chloroethane
- Freon 111
- Freon 113
- Hexachlorocyclohexane; Lindane
- Hexachloroethane
- Hexafluoroethane
- Methyl Bromide; Bromomethane
- Methylene Chloride; Dichloromethane
- Saturated Alkyl Halides
- Tetrachloroethane, 1,1,2,2
- Trichloroethane, 1,1,2
- Trichloroethane, 1,1,1; TCA
- Trichlorofluoromethane; Freon 11; Fluorocarbon 11
- Trichloropropane, 1,2,3

Secondary Alcohols
- Isobutyl Alcohol
- Propanol, 2; Isopropyl Alcohol; Isopropanol
- Secondary Alcohols

Secondary Aliphatic Amines
- HMX, Octagen, Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazine
- RDX, Cyclonite, Hexahydro-1,3,5-trinitro-1,3,5-triazine
- Secondary Aliphatic Amines

Selenium

Silicon Compounds—Other Significant
- Hexamethyldisilicon

Silver

Simple Aromatic Nitro Compounds
- Dinitrotoluene
- Nitrobenzene
- Simple Aromatic Nitro Compounds
- Trinitrotoluene; TNT

Single-Ring Heterocyclic Sulfur Compounds
- Single-Ring Heterocyclic Sulfur Compounds
- Tetrachlorothiophene

Sodium

Strontium

Sulfides, Disulfides
- Dimethyl Disulfide
- Dimethyl Sulfide
- Sulfides, Disulfides

Sulfonic Acids

Sulfonic Acids, Sulfoxides

Sulfoxides

Sulfur, Compounds and Ions

Sulfur Compounds
- Carbon Disulfide
- Hydrogen Sulfide
- Sulfur Oxides

Sulfur Compounds—Other Significant
- Sulfur Hexafluoride

Technetium

Tertiary Alcohols

Tertiary Amines (Alkyl, Aryl)
- Tertiary Amines (Alkyl, Aryl)

Thallium

Thiols
- Methanethiol; Methyl Mercaptan
- Thiols, Mercaptans

Thiols, Sulfides, and Disulfides

Thorium

Tin

Titanium

Total Petroleum Hydrocarbons (TPH)

Tungsten

Unsaturated Alkyl Halides
- Aldrin
- Chlordane; Octachlorohexahydromethanoindene
- Dichloroethene, 1,1
- Dichloroethene, 1,2; DCE
- Heptachlor
- Hexachlorobutadiene
- Hexachlorocyclopentadiene
- Tetrachloroethene; Perchloroethylene; PCE
- Toxaphene; Chlorinated Camphor
- Trichloroethene; Trichloroethylene; TCE
- Unsaturated Alkyl Halides
- Vinyl Chloride

Uranium

Vanadium

Volatile Organic Compounds (VOCs)

Zinc

Zirconium

TECHNOLOGIES APPLICABLE TO SPECIFIC CHEMICALS

ALCOHOLS

T0024 Air Stripping—General
T0101 Bio-Genesis Technologies, Aerobic Biotreatment System (ABS)
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0127 Blast Fracturing—General
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0161 Chemical Oxidation—General
T0196 Dames & Moore, Bioinfiltration
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0236 Electrokinetic Remediation—General
T0309 Fixed-Bed Soil Biofilters—General
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0408 In-Situ Fixation, Inc., Dual Auger System
T0422 InterBio, Petrobac
T0423 InterBio, Phenobac
T0467 KSE, Inc., AIR-II Process
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0494 ManTech Environmental Corporation, CleanOX Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0509 Metal-Based Permeable Reactive Barriers—General

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T0541 MYCELX Technologies Corporation, MYCELX
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0599 PerkinElmer, Inc., NoVOCs
T0606 PHYTOKinetics, Inc., Phytoremediation
T0617 PPC Biofilter
T0637 R.C. Costello and Associates, Inc., Actopentin Biomass Filter
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0802 ThermoRetec, Microbial Fence
T0817 T-Thermal Company, Submerged Quench Incineration
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0855 Vapor-Phase Biofiltration—General

ALDEHYDES

Aldehydes

T0108 Biomin, Inc., Organoclay
T0120 BioSystems Technology, Inc., Biosolids Enhanced Remediation (BER)
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0309 Fixed-Bed Soil Biofilters—General
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0541 MYCELX Technologies Corporation, MYCELX
T0607 Phytoremediation—General
T0617 PPC Biofilter
T0636 Quad Environmental Technologies Corporation, Chemtact Gaseous Waste Treatment
T0637 R.C. Costello and Associates, Inc., Actopentin Biomass Filter
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General

Butyraldehyde

T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0855 Vapor-Phase Biofiltration—General

Formaldehyde

T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0607 Phytoremediation—General
T0617 PPC Biofilter, Biofiltration Systems
T0636 Quad Environmental Technologies Corporation, Chemtact Gaseous Waste Treatment
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General

ALDEHYDES AND KETONES

T0024 Air Stripping—General
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0318 FRX, Inc., Hydraulic Fracturing
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0422 InterBio, Petrobac
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0541 MYCELX Technologies Corporation, MYCELX
T0617 PPC Biofilter, Biofiltration Systems
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0779 Terra Vac, Inc., Vacuum Extraction
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0855 Vapor-Phase Biofiltration—General

ALDEHYDES OR KETONES WITH OTHER FUNCTIONAL GROUPS

Aldehydes, Ketones with Other Functional Groups

T0056 Arctech, Inc., Light-Activated Reduction of Chemicals (LARC)
T0079 BasysTechnologies, Basys Biofilter
T0168 CleanSoil, Inc., The CleanSoil Process
T0726 Solidification/Stabilization—General
T0755 Supercritical Carbon Dioxide Extraction—General
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation

Kepone; Chlordecone

T0056 Arctech, Inc., Light-Activated Reduction of Chemicals (LARC)
T0726 Solidification/Stabilization—General
T0755 Supercritical Carbon Dioxide Extraction—General
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation

ALIPHATIC HYDROCARBONS

T0003 Abanaki Corporation, Active Belt Oil Skimmers
T0009 Advanced Environmental Services, Inc., System 64MT Low-Temperature Thermal Desorption
T0019 AER Labs, Landtreat Process
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0032 Alzeta Corporation, EDGE Thermal Processing Units
T0036 American Soil Technologies, Inc., Bio-Spin
T0047 Aqualogy BioRemedics, Environmental Quality NutriBac
T0050 Aquathermolysis—General
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0057 Arctech, Inc., Ozo-Detox
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0071 ASTEC, Inc./SPI Division Low-Temperature Thermal Desorption with Heat Recovery
T0075 B & S Research, Inc., B&S Achieve—B&S Industrial
T0078 Barr Engineering Company, Co-Burning Technology
T0091 BenCHEM, Inc., Soil Washing Technology
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0093 Bio Solutions, Inc., Soil Slurry—Sequencing Batch Reactor
T0095 Bio-Electrics, Inc., Electrofrac Detoxification System
T0096 BioEnviroTech, Inc., BioPetro
T0098 BioGee International, Inc., BioGee HC
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0100 BioGenesis Enterprises, Inc., Soil Remediation and Cleaning Products
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0104 Biogenie, Inc., Biogenie Biofiltration Process
T0108 Biomin, Inc., Organoclay
T0113 Bioremediation Service, Inc., AquaPlant Biofilter System
T0114 Bioremediation Technology Services, Inc., BTS Method
T0115 Bioscience, Inc., BIOX(TM) Biotreater
T0116 Bioscience, Inc., Microcat
T0117 Bioslurping—General
T0119 Biosurfactants—General
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0135 Calgon Carbon Corporation, Activated Carbon
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0139 Cancrete Environmental Solutions, Inc., Depocrete
T0142 Carlo Environmental Technologies, Inc., Medium Temperature Thermal Desorption (MTTD)
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0147 Catalytic Oxidation—General

T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0153 Certified Remediation Systems, Inc., CRS Process
T0157 CH2M Hill, Waterflood Oil Recovery
T0159 Charbon Consultants, HCZyme
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0161 Chemical Oxidation—General
T0164 ChemPete, Inc., Bioremediation
T0165 Cherokee Environmental Group, The Bio-Solution
T0168 CleanSoil, Inc., The CleanSoil Process
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0177 Conor Pacific, WINDsparge
T0178 Constructed Wetlands—General
T0182 ConTeck Environmental Services, Inc., Soil Roaster
T0186 Cosolvent Flushing—General
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0195 DAHL & Associates, Inc., ThermNet
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0201 Delta Cooling Towers, Inc., Aqua-Trim and Vanguard Air Strippers
T0202 Detox Industries, Inc., DETOX Process
T0204 Distillation—General
T0206 Divesco, Inc., Soil Washing
T0211 DRL Environmental Services, Enco-Tec RS-30 Thermal Desorption
T0212 Dual-Phase Extraction—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0217 Dutch Pride Products, EcoPlus
T0219 E Products, Inc., Venturi Thermal Oxidizer
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0228 ECO-TEC, Inc., EnviroMech Gold Biocatalytic Contaminant Degradation
T0233 Ejector Systems, Inc., VESTRIP
T0234 Ejector Systems, Inc., Stripperator
T0236 Electrokinetic Remediation—General
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0252 Energy Products of Idaho, Fluidized-Bed Combustion
T0253 Energy Reclamation, Inc., Pyrolytic Waste Reclamation (PWR)
T0256 Ensite, Inc., SafeSoil
T0259 ENSR International Group, Biovault
T0260 ENSR International Group, Soil Cleaning Process
T0261 Enviro Products, Inc., PetroTrap
T0267 Envirogen, Inc., Spartech
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE
T0270 EnviroLogical Engineering, Inc., Earthwise Formula 1
T0275 Environmental Fuel Systems, Inc., Reclaim
T0276 Environmental Recycling, L.L.C., Asphalt Stabilized Base/Engineered Backfill
T0277 Environmental Remediation Consultants, Inc., Biointegration

T0278 Environmental Remediation International (EnRem), Ltd., Soil Remediation System (SRS)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0290 Enviro-Soil Remediation, Inc., Thermal Stripping
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0300 ETUS, Inc., Enhanced Bioremediation
T0303 Extraksol (vendor unknown)
T0308 First Environment, Inc., FE ACTIVE
T0309 Fixed Bed Soil Biofilters—General
T0310 Fluidized-Bed Thermal Oxidation—General
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0321 Fungi Perfecti, Mycova Mycoremediation and Mycofiltration
T0323 G.E.M., Inc., Chemical Treatment
T0329 General Atomics, Supercritical Water Oxidation
T0331 Genesis Eco Systems, Inc., Soil Treatment and Recycling
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0342 Geo-Microbial Technologies, Inc., Metals Release and Removal from Wastes
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0348 GHEA Associates, Soil Washing Technology
T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0353 Golder Associates Corporation, Vertically Oriented Hydraulic Fracture Placed Iron Reactor Walls
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0364 Harding ESE, Inc., Bioremediation—Landfarming Treatment
T0365 Harding ESE, Inc., Composting
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0369 Heaven from Earth, Inc., Organic Cleaners
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0374 Horizontal Technologies, Inc., Linear Containment Remediation System
T0376 Horner & Company, Max Bac
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process In situ
T0380 Hrubetz Environmental Services, Inc., HRUBOUT Process, Ex Situ
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0386 Hydrocarbon Environmental Recovery Systems, Bioremediation Response Advancement Technologies (BRAT)
T0387 Hydrocarbon Technologies, Inc., Recovered Oil Pyrolysis and Extraction (ROPE)

T0388 Hydrogen Peroxide In Situ Bioremediation—General
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0400 IIT Research Institute, Radio Frequency Heating
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0402 Imperial Petroleum Recovery Corporation, MST 4000
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0411 Institute of Gas Technology Fluid Extraction—Biological Degradation
T0421 InterBio, Hydrobac
T0422 InterBio, Petrobac
T0423 InterBio, Phenobac
T0427 International Landmark Environmental, Inc., Aminoplast Capillary Technology
T0433 IT Corporation, Biofast
T0436 IT Corporation, Direct Application of Surfactants
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry Phase Bioremediation—Full Scale
T0448 IT Corporation, Slurry Phase Bioremediation—Pilot Scale
T0450 IT Corporation, Thermal Destruction Unit
T0454 KAL CON Environmental Services, Thermal Desorption
T0455 Kansas State University, Vibrorecovery
T0456 Keller Environmental, Inc., Bioinjection
T0457 KEMRON Environmental Services, Inc., Bioremediation—Soil and Groundwater
T0460 King, Buck Technologies, Inc., MultiMode Combustion
T0467 KSE, Inc., AIR-II Process
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0476 Lehigh University, Ground Rubber as a Reactive Permeable Barrier Sorption Media
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0487 Louisiana State University, Colloidal Gas Aphron
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0504 Medina Agricultural Products Company, Inc., Medina Bioremediation Products
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0516 Metcalf & Eddy, Inc., ORG-X
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0524 Microbes Research & Development, Inc., Uremel
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0530 MIOX Corporation, Miox System
T0532 Modified Natural Clays—General
T0533 Molasses Treatment for Bioremediation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0555 Niaski Environmental, Inc., Biopurge
T0556 Niaski Environmental, Inc., BioSparge System
T0558 NoChar, Inc., Petro-Bond
T0561 North American Drilling Technologies (NADT), Inc., EnviroZyme
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper

T0566 NUCON International, Inc., Brayton Cycle
T0576 Oil Waste Treatment Company, Terrazyme Phase Segregation
T0577 On-Site Technologies, Modular Interchangeable Treatment System (MITS)
T0578 OnSite Technology, L.L.C., Portable Indirect Thermal Desorption (ITD)
T0579 On-Site Thermal Services Division of Soil Restoration and Recycling, L.L.C., Low-Temperature Thermal Desorption Plant
T0580 Onsite*Ofsite, Inc., Petroleum Sludge Treatment
T0584 Osprey Biotechnics, Munox
T0591 Paragon Environmental Systems, Inc., Paragon SVE/Oxidizers
T0597 Pedco, Inc., Rotary Cascading Bed Incineration
T0599 PerkinElmer, Inc., NoVOCs
T0602 Pet-Con Soil Remediation, Inc., Thermal Desorption
T0603 Petro-Green, Inc., Petro-Green ADP-7
T0604 Philip Environmental Services Corporation, Thermal Recycling System
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0617 PPC Biofilter, Biofiltration Systems
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0621 Pressure Dewatering—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0626 Product Services Company, Oil Gator
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0633 Pyrovac International, Inc., Pyrocycling Process
T0635 QED Environmental Systems, Inc., Ferret In-Well Separator
T0638 R.E. Wright Environmental, Inc., Steam-Enhanced Recovery
T0639 R.E. Wright Environmental, Inc., In Situ Bioremediation Treatment System
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0644 Recra Environmental, Inc., Alternating Current Electrocoagulation
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0656 Remtech Engineers, Bubble Lance Low-Profile Diffused Air Stripper
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0676 Rusmar, Inc., Long-Duration Foam
T0677 Rust Federal Services, Inc., VAC*TRAX Thermal Desorption
T0680 S.S. Papadopulos & Associates, Inc., DeNAPLs (Detergent Extraction of NAPLs)
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0697 Science Remediation Services, Electro-Migration
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0707 Separation Dynamics, Inc., EXTRAN
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)

T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0718 Smith Technology Corporation, Two-Phase Vacuum Extraction
T0719 Soil/Sediment Washing—General
T0721 Soil Flushing—General
T0722 Soil Safe, Inc., Soil Recycling
T0724 Soil Technology, Inc., Soil Washing Treatability Study Unit
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0735 Sound Remedial Technologies, Inc., Hot Air Vapor Extraction (HAVE)
T0739 SRE, Inc., Solv-ex
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0750 Stevens Institute of Technology, Trench Bio-Sparge
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0760 Surtek, Inc., Surfactant Remediation
T0761 Sybron Chemicals, Inc., ABR (Augmented Bioreclamation) Microbial Blends
T0765 Technology Scientific, Ltd., Flow Consecutor Technology (FCT)
T0768 Tekno Associates, Biolift
T0769 Terra Resources, Ltd., Terra Wash Soil Washing
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual Vacuum Extraction
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0792 The Westford Chemical Corporation, BioSolv
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0799 ThermoChem, Inc., Pulse Enhanced Steam Reformer
T0802 ThermoRetec, Microbial Fence
T0804 ThermoRetec, Slurry Phase Bioremediation
T0805 ThermoRetec, Thermatek Thermal Desorption
T0809 Toronto Harbour Commissioners, Soil Recycle Treatment Train
T0810 Toxic Environmental Control Systems, Inc., Electrode-Assisted Soil Washing
T0811 TPS Technologies, Inc., Thermal Desorption
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0816 TRW Systems & Information Technology Group, Microbial Enhanced Recovery
T0818 TVIES, Inc., Soil Washing
T0829 U.S. Microbics, Inc., Bio-Raptor
T0831 U.S. Waste Thermal Processing, Model 100 Mobile Thermal Processor
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process

T0848 University of Southern California, Hybrid Microfiltration–Bioactive Carbon Process
T0857 Vendor Unknown, Calochroma Soil Washing
T0863 W.E.S., Inc., Microb-Sparging
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0869 Waste Microbes International (WMI), Inc., WMI-2000
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

ALIPHATIC NITRILES AND CYANATES

Acetonitrile

T0138 Calgon Carbon Corporation, Perox-Pure
T0334 Geo-Con, Inc., Shallow Soil Mixing/Thermally Enhanced Vapor Extraction
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0372 Hi-Point Industries, Ltd., Oclansorb
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process In Situ
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0531 Mirage Systems, Inc., ChemChar Process
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0891 Williams Environmental, RamSorb-1

Acrylonitrile

T0138 Calgon Carbon Corporation, Perox-Pure
T0355 Granular Activated Carbon (GAC)—General
T0596 Pecan-Based Granular Activated Carbon—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Aliphatic Nitriles

T0138 Calgon Carbon Corporation, Perox-Pure
T0334 Geo-Con, Inc., Shallow Soil Mixing/Thermally Enhanced Vapor Extraction
T0355 Granular Activated Carbon (GAC)—General
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0372 Hi-Point Industries, Ltd., Oclansorb
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process In Situ
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0531 Mirage Systems, Inc., ChemChar Process
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0596 Pecan-Based Granular Activated Carbon—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0891 Williams Environmental, RamSorb-1
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

ALIPHATIC NITROSAMINES

Aliphatic Nitrosamines

T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0775 Terra Vac, Inc., Dual Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation

N-Nitrosodimethylamine (NDMA)

T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0775 Terra Vac, Inc., Dual Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation

ALIPHATIC ORGANOPHOSPHOROUS COMPOUNDS

Aliphatic Organophosphorous Compounds

T0138 Calgon Carbon Corporation, Perox-Pure
T0168 CleanSoil, Inc., The CleanSoil Process
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0536 Molten Salt Oxidation—General

Dibutyl Phosphate

T0138 Calgon Carbon Corporation, Perox-Pure

Tributyl Phosphate

T0138 Calgon Carbon Corporation, Perox-Pure
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0536 Molten Salt Oxidation—General

ALKANES AND CYCLIC ALKANES

Alkanes and Cyclic Alkanes

T0011 Advanced Microbial Solutions, SuperBio
T0024 Air Stripping—General

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0032 Alzeta Corporation, EDGE Thermal Processing Units
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0084 Battelle Pacific Northwest Laboratory, Gas-Phase Corona Reactor
T0100 BioGenesis Enterprises, Inc., Soil Remediation and Cleaning Products
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0108 Biomin, Inc., Organoclay
T0126 Bioventing—General
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., The CleanSoil Process
T0208 Donald L. Geisel & Associates, Inc., HeatTrode Thermally Accelerated In Situ Bioremediation
T0212 Dual Phase Extraction—General
T0236 Electrokinetic Remediation—General
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0292 EnviroWall, Inc., EnviroWall Barrier
T0309 Fixed Bed Soil Biofilters—General
T0318 FRX, Inc., Hydraulic Fracturing
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0372 Hi-Point Industries, Ltd., Oclansorb
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0411 Institute of Gas Technology, Fluid Extraction—Biological Degradation
T0455 Kansas State University, Vibrorecovery
T0456 Keller Environmental, Inc., Bioinjection
T0467 KSE, Inc., AIR-II Process
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0487 Louisiana State University, Colloidal Gas Aphron
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0520 Methanotrophic Biofilters—General
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0533 Molasses Treatment for Bioremediation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0595 Peat/Compost Biofiltration—General
T0617 PPC Biofilter, Biofiltration Systems
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0654 Remediation Service International, Internal Combustion Engine (ICE)

T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services, Inc., and Integrated Water Resources Steam-Enhanced Extraction (SEE)
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0855 Vapor-Phase Biofiltration—General
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0891 Williams Environmental, RamSorb-1
T0898 Zapit Technology, Inc., Zapit Processing Unit

Cyclohexane

T0011 Advanced Microbial Solutions, SuperBio
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0138 Calgon Carbon Corporation, Perox-Pure
T0168 CleanSoil, Inc., CleanSoil Process
T0212 Dual Phase Extraction—General
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0318 FRX, Inc., Hydraulic Fracturing
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0355 Granular Activated Carbon (GAC)—General
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0756 Supercritical Water Oxidation—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0794 Thermal Desorption—General
T0891 Williams Environmental, RamSorb-1

Decane, *n*

T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery

T0126 Bioventing—General
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0755 Supercritical Carbon Dioxide Extraction—General
T0794 Thermal Desorption—General

Heptanes

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0126 Bioventing—General
T0208 Donald L. Geisel & Associates, Inc., HeatTrode Thermally Accelerated In Situ Bioremediation
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0346 Geotech Environmental Equipment Inc., Scavenger Recovery Systems
T0355 Granular Activated Carbon (GAC)—General
T0372 Hi-Point Industries, Ltd., Oclansorb
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0617 PPC Biofilter, Biofiltration Systems
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0855 Vapor-Phase Biofiltration—General
T0891 Williams Environmental, RamSorb-1

Hexadecane

T0126 Bioventing—General
T0161 Chemical Oxidation—General
T0455 Kansas State University, Vibrorecovery
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0755 Supercritical Carbon Dioxide Extraction—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells

Hexanes

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0126 Bioventing—General
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0355 Granular Activated Carbon (GAC)—General
T0372 Hi-Point Industries, Ltd., Oclansorb
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0456 Keller Environmental, Inc., Bioinjection
T0467 KSE, Inc., AIR-II Process
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0595 Peat/Compost Biofiltration—General
T0654 Remediation Service International, Internal Combustion Engine (ICE)

T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0779 Terra Vac, Inc., Vacuum Extraction

Isobutane

T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0309 Fixed-Bed Soil Biofilters—General
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0855 Vapor-Phase Biofiltration—General

Methane

T0084 Battelle Pacific Northwest Laboratory, Gas-Phase Corona Reactor
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0292 EnviroWall, Inc., EnviroWall Barrier
T0520 Methanotrophic Biofilters—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0855 Vapor-Phase Biofiltration—General
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon

Methyl Cyclohexane

T0011 Advanced Microbial Solutions, SuperBio
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads

Nonane

T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0126 Bioventing—General
T0208 Donald L. Geisel & Associates, Inc., HeatTrode Thermally Accelerated In Situ Bioremediation
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0794 Thermal Desorption—General

Octane, iso; Isooctane

T0126 Bioventing—General
T0208 Donald L. Geisel & Associates, Inc., HeatTrode Thermally Accelerated In Situ Bioremediation
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0355 Granular Activated Carbon (GAC)—General
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

Pentanes

T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0467 KSE, Inc., AIR-II Process
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0891 Williams Environmental, RamSorb-1

Propane

T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0309 Fixed-Bed Soil Biofilters—General
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0855 Vapor-Phase Biofiltration—General

ALKENES, CYCLIC ALKENES, AND DIENES

Alkenes, Cyclic Alkenes, and Dienes

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0032 Alzeta Corporation, EDGE Thermal Processing Units
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0108 Biomin, Inc., Organoclay
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0236 Electrokinetic Remediation—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0289 EnviroSep, Inc., Thick-Film Absorption (TFA)
T0308 First Environment, Inc., FE ACTIVE
T0318 FRX, Inc., Hydraulic Fracturing
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0348 GHEA Associates, Soil Washing Technology
T0353 Golder Associates Corporation, Vertically Oriented Hydraulic Fracture Placed Iron Reactor Walls
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0487 Louisiana State University, Colloidal Gas Aphron
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0533 Molasses Treatment for Bioremediation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0625 Process Technologies, Inc., Photolytic Destruction Technology

T0676 Rusmar, Inc., Long-Duration Foam
T0747 SteamTech Environmental Services, Inc., and Integrated Water Resources Steam-Enhanced Extraction (SEE)
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0855 Vapor-Phase Biofiltration—General
T0870 Waste Stream Technology, Inc., Bioremediation
T0894 Xerox Corporation, Two-Phase Extraction System
T0898 Zapit Technology, Inc., Zapit Processing Unit

Ethylene

T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0855 Vapor-Phase Biofiltration—General
T0870 Waste Stream Technology, Inc., Bioremediation

Propylene

T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

ALKYL HALIDES

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0085 Battelle Pacific Northwest Laboratory, Subsurface Lithoautotrophic Microbial Ecosystem (SLiME)
T0108 Biomin, Inc., Organoclay
T0135 Calgon Carbon Corporation, Activated Carbon
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0178 Constructed Wetlands—General
T0223 Earth Tech Bioremediation—Solid Phase
T0236 Electrokinetic Remediation—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0490 M4 Environmental, L.P., Catalytic Extraction Process

T0509 Metal-Based Permeable Reactive Barriers—General
T0525 Microbial & Aquatic Treatment Systems, Inc., (MATS) Biomats
T0533 Molasses Treatment for Bioremediation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0676 Rusmar, Inc., Long-Duration Foam
T0689 SBP Technologies, Inc., Membrane Filtration
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0853 UV Technologies, Inc., UV-CATOX Technology

ALKYNES

T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General

ALUMINUM

T0001 3M Company, 3M Empore Extraction Disk
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0054 Arctech, Inc., Humasorb
T0107 Biomet Mining Solutions Corporation, Biosulfide Process
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0149 Cement-Based Stabilization/Solidification—General
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0174 Commodore Separation Technologies, Inc., Supported Liquid Membrane
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0214 DuPont/Oberlin, Microfiltration Technology
T0230 EET Corporation, Microwaste Waste Solidification
T0232 Eichrom Industries, Inc., Diphonix
T0235 Electrochemical Treatment of Contaminated Ground Water—General
T0279 Environmental Research and Development, Inc., The Neutral Process for Heavy Metals Removal

T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0307 Filter Flow Technology, Inc., Colloid Polishing Filter Method
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0378 HPT Research, Inc., Ionic State Modification (ISM) Process for the Treatment of Acid Mine Drainage
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0452 Joule-Heated Vitrification—General
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System
T0615 Polymer-Based Solidification/Stabilization—General
T0616 Pozzolanic Solidification/Stabilization—General
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0692 SCC Environmental, Micro-Flo
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0726 Solidification/Stabilization—General
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0801 Thermoplastic Stabilization/Solidification—General
T0808 Toledo Engineering Co., Inc., High-Temperature Joule-Heated Vitrification
T0819 U.S. Department of Energy Laboratories, Enhanced Sludge Washing
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon

AMERICIUM

T0005 Active Environmental Technologies, Inc., TechXtract
T0058 Arctic Foundations, Inc., Cryogenic Barrier
T0059 Argonne National Laboratory, Advanced Integrated Solvent Extraction and Ion Exchange Systems
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0064 Argonne National Laboratory, Magnetically Assisted Chemical Separation (MACS)
T0066 Argonne National Laboratory, Transuranium Extraction (TRUEX) Process
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0230 EET Corporation, Microwaste Waste Solidification
T0232 Eichrom Industries, Inc., Diphonix
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0344 Geosafe Corporation, In Situ Vitrification
T0509 Metal-Based Permeable Reactive Barriers—General
T0546 Natural Attenuation—General
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0601 Permeable Reactive Barriers (PRBs)—General

T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0798 Thermo NUClean, Segmented Gate System (SGS)
T0808 Toledo Engineering Co., Inc., High-Temperature Joule-Heated Vitrification
T0819 U.S. Department of Energy Laboratories, Enhanced Sludge Washing

AMIDES

Amides

T0010 Advanced Manufacturing and Development, Inc., Advanced Bio-Gest System
T0050 Aquathermolysis—General
T0175 Composting—General
T0355 Granular Activated Carbon (GAC)—General
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0546 Natural Attenuation—General

Carbofuran

T0010 Advanced Manufacturing and Development, Inc., Advanced Bio-Gest System
T0175 Composting—General
T0355 Granular Activated Carbon (GAC)—General
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0546 Natural Attenuation—General

Dimethyl Acetamide

T0490 M4 Environmental, L.P., Catalytic Extraction Process

AMINES

T0001 3M Company, 3M Empore Extraction Disk
T0098 BioGee International, Inc., BioGee HC
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0178 Constructed Wetlands—General
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0309 Fixed Bed Soil Biofilters—General
T0355 Granular Activated Carbon (GAC)—General
T0384 Hydraulic Fracturing—General
T0423 InterBio, Phenobac
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0637 R.C. Costello and Associates, Inc., Actopentin Biomass Filter
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)

T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0756 Supercritical Water Oxidation—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0800 ThermoEnergy Corporation, NitRem
T0817 T-Thermal Company, Submerged Quench Incineration
T0855 Vapor-Phase Biofiltration—General
T0877 Weatherly, Inc., AQUA CRITOX (R)

ANTIMONY

T0131 Brice Environmental Services Corporation (BESCORP), Soil Washing System (BSWS)
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0207 Doe Run Company, TERRAMET Heavy-Metal Removal Technology
T0232 Eichrom Industries, Inc., Diphonix
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0291 EnviroSource Technologies, Inc., Super Detox Process
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0313 Forrester Environmental Services, Inc., Heavy-Metal Stabilization
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0510 Metals Recovery, Inc., Metals Leaching
T0518 Met-Chem, Metal Kleen A
T0519 Met-Chem, Metal Kleen B (MCB)
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0789 Texilla Environmental, Inc., Synthetic Mineral Immobilization Technology (SMITE)

AROMATIC AMINES AND DIAMINES

Aniline

T0024 Air Stripping—General
T0135 Calgon Carbon Corporation, Activated Carbon
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0180 Constructed Wetlands for Explosives Contamination—General
T0320 Funderburk & Associates, Solidification Process
T0352 Golder Associates Corporation, Montan Wax Barrier
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation

T0406 In Situ Soil Vapor Extraction (SVE)—General
T0531 Mirage Systems, Inc., ChemChar Process
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0775 Terra Vac, Inc., Dual Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0853 UV Technologies, Inc., UV-CATOX Technology

Aromatic Amines and Diamines

T0001 3M Company, 3M Empore Extraction Disk
T0010 Advanced Manufacturing and Development, Inc., Advanced Bio-Gest System
T0024 Air Stripping—General
T0044 Applied Natural Sciences, Inc., TreeMediation
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol Inc., Soil Washing Technology
T0135 Calgon Carbon Corporation, Activated Carbon
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0180 Constructed Wetlands for Explosives Contamination—General
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0320 Funderburk & Associates, Solidification Process
T0352 Golder Associates Corporation, Montan Wax Barrier
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0416 Intech One Eighty, White-Rot Fungus
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0531 Mirage Systems, Inc., ChemChar Process
T0546 Natural Attenuation—General
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0755 Supercritical Carbon Dioxide Extraction—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General

T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0853 UV Technologies, Inc., UV-CATOX Technology
T0889 White-Rot Fungus—General

Atrazine

T0001 3M Company, 3M Empore Extraction Disk
T0010 Advanced Manufacturing and Development, Inc., Advanced Bio-Gest System
T0044 Applied Natural Sciences, Inc., TreeMediation
T0135 Calgon Carbon Corporation, Activated Carbon
T0168 CleanSoil, Inc., CleanSoil Process
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0546 Natural Attenuation—General
T0607 Phytoremediation—General
T0755 Supercritical Carbon Dioxide Extraction—General
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General

Benzidine

T0001 3M Company, 3M Empore Extraction Disk
T0124 BioTrol, Inc., Soil Washing Technology
T0161 Chemical Oxidation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0853 UV Technologies, Inc., UV-CATOX Technology

Chloroaniline, 4

T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0416 Intech One Eighty, White-Rot Fungus
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0853 UV Technologies, Inc., UV-CATOX Technology
T0889 White-Rot Fungus—General

Chloroaniline(bis) Methylene; Methylene Bis(chloroaniline); MBOCA; Dichlorodiaminodiphenyl Methane

T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0794 Thermal Desorption—General
T0889 White-Rot Fungus—General

Dichlorobenzidine, 3,3

T0001 3M Company, 3M Empore Extraction Disk
T0124 BioTrol, Inc., Soil Washing Technology
T0606 PHYTOKinetics, Inc., Phytoremediation
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General

Propazine

T0001 3M Company, 3M Empore Extraction Disk
T0138 Calgon Carbon Corporation, Perox-Pure
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)

AROMATIC NITRILES AND CYANATES

Aromatic Nitriles

T0050 Aquathermolysis—General
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0365 Harding ESE, Inc., Composting
T0490 M4 Environmental, L.P., Catalytic Extraction Process

Toluene Diisocyanate

T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0490 M4 Environmental, L.P., Catalytic Extraction Process

AROMATIC NITRO COMPOUNDS

T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0236 Electrokinetic Remediation—General
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0395 Idaho Research Foundation, Inc., and White Shield, Inc., Simplot Anaerobic Biological Remediation (SABRE)
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0533 Molasses Treatment for Bioremediation—General

AROMATIC NITRO COMPOUNDS WITH OTHER FUNCTIONAL GROUPS

Aromatic Nitro Compounds with Other Functional Groups

T0138 Calgon Carbon Corporation, Perox-Pure
T0236 Electrokinetic Remediation—General
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0395 Idaho Research Foundation, Inc., and White Shield, Inc., Simplot Anaerobic Biological Remediation (SABRE)
T0414 Institute of Gas Technology, SELPhOx
T0755 Supercritical Carbon Dioxide Extraction—General

Pentachloronitrobenzene

T0138 Calgon Carbon Corporation, Perox-Pure
T0755 Supercritical Carbon Dioxide Extraction—General

AROMATIC ORGANOPHOSPHOROUS COMPOUNDS

Aromatic Organophosphorous Compounds

T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0546 Natural Attenuation—General
T0601 Permeable Reactive Barriers (PRBs)—General
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0755 Supercritical Carbon Dioxide Extraction—General
T0817 T-Thermal Company, Submerged Quench Incineration

Parathion

T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0546 Natural Attenuation—General
T0601 Permeable Reactive Barriers (PRBs)—General
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0755 Supercritical Carbon Dioxide Extraction—General
T0817 T-Thermal Company, Submerged Quench Incineration

AROMATICS WITH HALOGENATED SIDE CHAIN

Aromatics with Halogenated Side Chain

T0001 3M Company, 3M Empore Extraction Disk
T0114 Bioremediation Technology Services, Inc., BTS Method
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0124 BioTrol, Inc., Soil Washing Technology
T0135 Calgon Carbon Corporation, Activated Carbon
T0168 CleanSoil, Inc., CleanSoil Process
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)

T0343 Georgia Institute of Technology, Construction Research Center In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0416 Intech One Eighty, White-Rot Fungus
T0452 Joule-Heated Vitrification—General
T0499 Maxymillian Technologies, Inc., Indirect System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0579 On-Site Thermal Services Division of Soil Restoration and Recycling, L.L.C., Low-Temperature Thermal Desorption Plant
T0601 Permeable Reactive Barriers (PRBs)—General
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0732 Solvent Extraction—General
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0759 Surfactants—General
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0817 T-Thermal Company, Submerged Quench Incineration
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0889 White-Rot Fungus—General

Benzyl Chloride; Chlorotoluene, Alpha

T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

DDT; Trichloro(chlorophenyl,4- bis) Ethane

T0001 3M Company, 3M Empore Extraction Disk
T0114 Bioremediation Technology Services, Inc., BTS Method
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0124 BioTrol, Inc., Soil Washing Technology
T0135 Calgon Carbon Corporation, Activated Carbon

T0168 CleanSoil, Inc., The CleanSoil Process
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0343 Georgia Institute of Technology, Construction Research Center In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0416 Intech One Eighty, White-Rot Fungus
T0452 Joule-Heated Vitrification—General
T0499 Maxymillian Technologies, Inc., Indirect System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0579 On-Site Thermal Services Division of Soil Restoration and Recycling, L.L.C., Low-Temperature Thermal Desorption Plant
T0601 Permeable Reactive Barriers (PRBs)—General
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T0607 Phytoremediation—General
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T0732 Solvent Extraction—General
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0759 Surfactants—General
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0817 T-Thermal Company, Submerged Quench Incineration
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0889 White-Rot Fungus—General

ARSENIC

T0005 Active Environmental Technologies, Inc., TechXtract
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0054 Arctech, Inc., Humasorb
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0076 B & W Services, Inc., Cyclone Furnace Vitrification

T0088 Battelle Pacific Northwest National Laboratory, Terra-VIT Vitrification Technology
T0090 Beco Engineering Company, Alka/Sorb
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0127 Blast Fracturing—General
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0149 Cement-Based Stabilization/Solidification—General
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0161 Chemical Oxidation—General
T0169 Clemson University, Sintered Ceramic Stabilization
T0176 Concurrent Technologies Corporation, Acid Extraction Treatment System (AETS)
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0186 Cosolvent Flushing—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0200 Delphi Research, Inc., DETOX
T0218 Dynaphore, Inc., Forager Sponge Technology
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0235 Electrochemical Treatment of Contaminated Groundwater—General
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0279 Environmental Research and Development, Inc., The Neutral Process for Heavy Metals Removal
T0285 Environmental Technology (U.S.), Inc., TR-Detox
T0291 EnviroSource Technologies, Inc., Super Detox Process
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0306 Ferro Corporation, Waste Vitrification Through Electric Melting
T0307 Filter Flow Technology, Inc., Colloid Polishing Filter Method
T0313 Forrester Environmental Services, Inc., Heavy-Metal Stabilization
T0320 Funderburk & Associates, Solidification Process
T0322 G.E.M., Inc., Treatment of Chromated Copper Arsenate (CCA) in Wood Products
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0340 Geo-Microbial Technologies, Inc., Heteroatom Extraction Technology
T0343 Georgia Institute of Technology, Construction Research Center In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0377 Horsehead Resource Development Company, Inc., Flame Reactor
T0378 HPT Research, Inc., Ionic State Modification (ISM) Process for the Treatment of Acid Mine Drainage
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0410 Institute of Gas Technology, AGGCOM
T0418 Integrated Chemistries, Inc., Metraxt
T0426 International Environmental Trading Company, Inc., Metals Extraction and Recycling System
T0443 IT Corporation, In Situ Geochemical Fixation

T0450 IT Corporation, Thermal Destruction Unit
T0452 Joule-Heated Vitrification—General
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0466 Krudico, Inc., Ion Exchange Resins for Nitrate & Perchlorate
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0509 Metal-Based Permeable Reactive Barriers—General
T0510 Metals Recovery, Inc., Metals Leaching
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0518 Met-Chem, Metal Kleen A
T0519 Met-Chem, Metal Kleen B (MCB)
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0531 Mirage Systems, Inc., ChemChar Process
T0533 Molasses Treatment for Bioremediation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0554 New Mexico Institute of Mining and Technology, Surfactant—Modified Zeolite
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0594 PEAT, Inc., Thermal Destruction and Recovery
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0601 Permeable Reactive Barriers (PRBs)—General
T0605 Physical Sciences, Inc., Metals Immobilization and Decontamination of Aggregate Solids (MeIDAS)
T0607 Phytoremediation—General
T0611 Pintail Systems, Inc., Spent Ore Bioremediation Process
T0613 Plasma Vitrification—General
T0615 Polymer-Based Solidification/Stabilization—General
T0616 Pozzolanic Solidification/Stabilization—General
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0667 RMT, Inc., Metal Treatment Technology (MTT)
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0691 SBP Technologies, Inc., Solid Phase Bioremediation
T0692 SCC Environmental, Micro-Flo
T0696 Science Applications International Corporation, Plasma Hearth Process
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0726 Solidification/Stabilization—General
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0730 Solucorp Industries, Ltd., Molecular Bonding System
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0741 Stark Encapsulation, Inc., METLCAP Chemical Cement
T0742 Starmet Corporation, RocTec Stabilization
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0763 Tallon, Inc., Virtokele

T0772 Terra Vac, Geochemical Fixation
T0773 Terra Vac, Heap Leaching
T0787 Texaco, Inc., Texaco Gasification Process
T0789 Texilla Environmental, Inc., Synthetic Mineral Immobilization Technology (SMITE)
T0794 Thermal Desorption—General
T0808 Toledo Engineering Co., Inc., High-Temperature Joule-Heated Vitrification
T0810 Toxic Environmental Control Systems, Inc., Electrode Assisted Soil Washing
T0815 Trigon Group, L.L.C., ARCHON In Situ Mixer
T0817 T-Thermal Company, Submerged Quench Incineration
T0818 TVIES, Inc., Soil Washing
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0849 University of Washington, Metals Treatment by Adsorptive Filtration
T0862 Vortec Corporation, Cyclone Melting System (CMS)
T0874 Water Technology International Corporation, Self-Sealing/Self-Healing Barrier (SS/SH)
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0899 Zenon Environmental Systems, Inc., ZenoGem

AZO COMPOUNDS

Azo Compounds

T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0124 BioTrol, Inc., Soil Washing Technology
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0889 White Rot Fungus—General

Azobenzene

T0124 BioTrol, Inc., Soil Washing Technology
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)

AZO COMPOUNDS, HYDRAZINE DERIVATIVES

T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)

BARIUM

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0015 Advanced Recovery Systems, Inc., DeHg
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0054 Arctech, Inc., Humasorb
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0076 B & W Services, Inc., Cyclone Furnace Vitrification

T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0200 Delphi Research, Inc., DETOX
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0291 EnviroSource Technologies, Inc., Super Detox Process
T0320 Funderburk & Associates, Solidification Process
T0343 Georgia Institute of Technology, Construction Research Center In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0359 GTS Duratek, DuraMelter
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0450 IT Corporation, Thermal Destruction Unit
T0452 Joule-Heated Vitrification—General
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0510 Metals Recovery, Inc., Metals Leaching
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0546 Natural Attenuation—General
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0594 PEAT, Inc., Thermal Destruction and Recovery
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0613 Plasma Vitrification—General
T0624 Proactive Applied Solutions Corporation, LEADX
T0644 Recra Environmental, Inc., Alternating Current Electrocoagulation
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0692 SCC Environmental, Micro-Flo
T0696 Science Applications International Corporation, Plasma Hearth Process
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0741 Stark Encapsulation, Inc., METLCAP Chemical Cement
T0742 Starmet Corporation, RocTec Stabilization
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0808 Toledo Engineering Co., Inc., High-Temperature Joule-Heated Vitrification
T0818 TVIES, Inc., Soil Washing
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0862 Vortec Corporation, Cyclone Melting System (CMS)

BENZENE AND MONOSUBSTITUTED BENZENE HYDROCARBONS

Benzene

T0011 Advanced Microbial Solutions, SuperBio
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0020 Aeration Basins—General
T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0041 AP Technologies, Inc., Mercrobes Mercury Reduction Technology
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0049 Aqualogy BioRemedics, OptiSorb Encapsulate
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0054 Arctech, Inc., Humasorb
T0067 Ariel Industries, Inc., Ariel SST Low-Temperature Thermal Desorber
T0068 Armstrong Laboratory, Environics Directorate Phase-Transfer Oxidation
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0084 Battelle Pacific Northwest Laboratory, Gas-Phase Corona Reactor
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0093 Bio Solutions, Inc., Soil Slurry—Sequencing Batch Reactor
T0096 BioEnviroTech, Inc., BioPetro
T0098 BioGee International, Inc., BioGee HC
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0104 Biogenie, Inc., Biogenie Biofiltration Process
T0105 Biogenie, Inc., Biogenie Biopile
T0106 Biological Activated Carbon—General
T0108 Biomin, Inc., Organoclay
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0113 Bioremediation Service, Inc., AquaPlant Biofilter System
T0114 Bioremediation Technology Services, Inc., BTS Method
T0117 Bioslurping—General
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0142 Carlo Environmental Technologies, Inc., Medium Temperature Thermal Desorption (MTTD)
T0143 Carson Environmental, Low-Temperature Oxidation
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery

T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0158 CH2M Hill, Phytoremediation-Based Systems
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0164 ChemPete, Inc., Bioremediation
T0168 CleanSoil, Inc., CleanSoil Process
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0177 Conor Pacific, WINDsparge
T0178 Constructed Wetlands—General
T0182 ConTeck Environmental Services, Inc., Soil Roaster
T0185 Corrpro Companies Incorporated, Electroremediation
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0193 Current Environmental Solutions, L.L.C., In Situ Corona
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0197 Dames and Moore, Two-Phase Vacuum Extraction
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0200 Delphi Research, Inc., DETOX
T0201 Delta Cooling Towers, Inc., Aqua-Trim and Vanguard Air Strippers
T0202 Detox Industries, Inc., DETOX Process
T0208 Donald L. Geisel & Associates, Inc., HeatTrode Thermally Accelerated In Situ Bioremediation
T0212 Dual Phase Extraction—General
T0222 Earth Purification Engineering, Inc., Soil Cleanup System (SCS)
T0223 Earth Tech Bioremediation—Solid Phase
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0228 ECO-TEC, Inc., EnviroMech Gold Biocatalytic Contaminant Degradation
T0231 EFX Systems, Inc., Granular Activated Carbon-Fluidized Bed Reactor (GAC FBR) Process
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0256 Ensite, Inc., SafeSoil
T0257 EnSolve Biosystems, Inc., EnCell Bioreactor
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0278 Environmental Remediation International (EnRem), Ltd., Soil Remediation System (SRS)
T0281 Environmental Resources Management Corporation (ERM), Advanced Fluidized Composting (AFC)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0289 EnviroSep, Inc., Thick Film Absorption (TFA)
T0290 Enviro-Soil Remediation, Inc., Thermal Stripping

T0292 EnviroWall, Inc., EnviroWall Barrier
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0295 EOD Technology, Inc., Biotechnical Processing of Explosives
T0299 ETG Environmental, Inc., Thermo-O-Detox Medium Temperature Thermal Desorption (MTTD)
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0309 Fixed Bed Soil Biofilters—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0329 General Atomics, Supercritical Water Oxidation
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0344 Geosafe Corporation, In Situ Vitrification
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0348 GHEA Associates, Soil Washing Technology
T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0355 Granular Activated Carbon (GAC)—General
T0356 Groundwater Recovery Systems, Inc., OXY 1
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume-Interception Treatment Technology
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process, In Situ
T0380 Hrubetz Environmental Services, Inc., HRUBOUT Process, Ex Situ
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0388 Hydrogen Peroxide, In Situ Bioremediation—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0405 In Situ Oil Skimmers—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0412 Institute of Gas Technology, MGP-REM
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0423 InterBio, Phenobac
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0434 IT Corporation, Biological Polishing Treatment
T0438 IT Corporation, Enhanced Natural Degradation (END)
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0454 KAL CON Environmental Services, Thermal Desorption
T0457 KEMRON Environmental Services, Inc., Bioremediation—Soil and Groundwater

T0458 Kenox Technology Corporation, Wet Air Oxidation
T0459 King, Buck Technologies, Inc., HD CatOx System
T0460 King, Buck Technologies, Inc., MultiMode Combustion
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0476 Lehigh University, Ground Rubber as a Reactive Permeable Barrier Sorption Media
T0489 M.L. Chartier, Inc., The Therminator
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0495 Maple Engineering Services, Inc., Biopur
T0496 MARCOR Remediation, Inc., Advanced Chemical Treatment
T0497 Massachusetts Institute of Technology, Tunable Hybrid Plasma
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0500 Maxymillian Technologies, Inc., Thermal Desorption System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0504 Medina Agricultural Products Company, Inc., Medina Bioremediation Products
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0511 Metals Removal Via Peat—General
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0532 Modified Natural Clays—General
T0541 MYCELX Technologies Corporation, MYCELX
T0546 Natural Attenuation—General
T0547 NEPCCO Environmental Systems, SoilPurge
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0554 New Mexico Institute of Mining and Technology Surfactant-Modified Zeolite
T0555 Niaski Environmental, Inc., Biopurge
T0556 Niaski Environmental, Inc., BioSparge System
T0561 North American Drilling Technologies (NADT), Inc., EnviroZyme
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0566 NUCON International, Inc., Brayton Cycle
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0577 On-Site Technologies, Modular Interchangeable Treatment System (MITS)
T0578 OnSite Technology, L.L.C., Portable Indirect Thermal Desorption (ITD)
T0584 Osprey Biotechnics, Munox
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0592 Passive Soil Vapor Extraction—General
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0595 Peat/Compost Biofiltration—General

T0596 Pecan-Based Granular Activated Carbon—General
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0602 Pet-Con Soil Remediation, Inc., Thermal Desorption
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0617 PPC Biofilter, Biofiltration Systems
T0618 Praxair, Inc., MixFlo
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0626 Product Services Company, Oil Gator
T0628 PTC Enterprises, BioTreat System
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0631 Purus, Inc., Pulsed UV Irradiation
T0638 R.E. Wright Environmental, Inc., Steam Enhanced Recovery
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0656 Remtech Engineers, Bubble Lance Low-Profile Diffused Air Stripper
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0676 Rusmar, Inc., Long-Duration Foam
T0680 S.S. Papadopulos & Associates, Inc., DeNAPLs (Detergent Extraction of NAPLs)
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0689 SBP Technologies, Inc., Membrane Filtration
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0732 Solvent Extraction—General
T0733 Sonotech, Inc., Cello Pulse Combustion BurnerSystem
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services, Inc., and Integrated Water Resources Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0750 Stevens Institute of Technology, Trench Bio-Sparge
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0756 Supercritical Water Oxidation—General

T0759 Surfactants—General
T0761 Sybron Chemicals, Inc., ABR (Augmented Bioreclamation) Microbial Blends
T0764 Tarmac Environmental Company, Inc., Thermal Desorption
T0768 Tekno Associates, Biolift
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0771 Terra Vac, DNAPL Vaporization
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0792 The Westford Chemical Corporation, BioSolv
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0802 ThermoRetec, Microbial Fence
T0805 ThermoRetec, Thermatek Thermal Desorption
T0807 Thorneco, Inc., Enzyme-Activated Cellulose Technology
T0811 TPS Technologies, Inc. Thermal Desorption
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0817 T-Thermal Company, Submerged Quench Incineration
T0825 U.S. Filter, Ultrox Peroxone Oxidation
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0835 Umpqua Research Company, Low-Temperature Aqueous Phase Catalytic Oxidation
T0845 University of Dayton, Research Institute Photothermal Detoxification Unit
T0847 University of New South Wales, Upflow Washing
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0863 W.E.S., Inc., Microb-Sparging
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0870 Waste Stream Technology, Inc., Bioremediation
T0873 Water Equipment Services, Inc., Environmental Division Vacu-Point
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0884 Westinghouse Savannah River Company, In Situ Bioremediation of Chlorinated Solvents with Natural Gas
T0890 WIK Associates, Inc., Bugs+Plus
T0891 Williams Environmental, RamSorb-1
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0899 Zenon Environmental Systems, Inc., ZenoGem
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Benzene and Monosubstituted Benzene Hydrocarbons

T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0020 Aeration Basins—General
T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0033 Ambient Engineering, Inc., BIOTON
T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0041 AP Technologies, Inc., Mercrobes Mercury Reduction Technology
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0049 Aqualogy BioRemedics, OptiSorb Encapsulate
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0054 Arctech, Inc., Humasorb
T0067 Ariel Industries, Inc., Ariel SST Low-Temperature Thermal Desorber
T0068 Armstrong Laboratory Environics Directorate, Phase-Transfer Oxidation
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0084 Battelle Pacific Northwest Laboratory, Gas-Phase Corona Reactor
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0093 Bio Solutions, Inc., Soil Slurry—Sequencing Batch Reactor
T0096 BioEnviroTech, Inc., BioPetro
T0098 BioGee International, Inc., BioGee HC
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0101 Bio-Genesis Technologies, Aerobic Biotreatment System (ABS)
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0104 Biogenie, Inc., Biogenie Biofiltration Process
T0105 Biogenie, Inc., Biogenie Biopile
T0106 Biological Activated Carbon—General
T0108 Biomin, Inc., Organoclay
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0113 Bioremediation Service, Inc., AquaPlant Biofilter System
T0114 Bioremediation Technology Services, Inc., BTS Method
T0115 Bioscience, Inc., BIOX Biotreater
T0117 Bioslurping—General
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0122 Biotrickling Filter—General
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0129 Bogart Environmental Services, Inc., MiKIE
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure

T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0143 Carson Environmental, Low-Temperature Oxidation
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0158 CH2M Hill, Phytoremediation-based Systems
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0164 ChemPete, Inc., Bioremediation
T0166 Cintec Environment, Inc., Circulating Fluidized Bed Combustor (CFBC)
T0168 CleanSoil, Inc., The CleanSoil Process
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0177 Conor Pacific, WINDsparge
T0178 Constructed Wetlands—General
T0182 ConTeck Environmental Services, Inc., Soil Roaster
T0185 Corrpro Companies Incorporated, Electroremediation
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0188 Croy Dewatering & Environmental Services, Inc., Dual Phase Recovery Unit
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0193 Current Environmental Solutions, L.L.C., In Situ Corona
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0197 Dames and Moore, Two-Phase Vacuum Extraction
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0200 Delphi Research, Inc., DETOX
T0201 Delta Cooling Towers, Inc., Aqua-Trim and Vanguard Air Strippers
T0202 Detox Industries, Inc., DETOX Process
T0208 Donald L. Geisel & Associates, Inc., HeatTrode Thermally Accelerated In Situ Bioremediation
T0212 Dual Phase Extraction—General
T0215 DuraTherm, Inc., DuraTherm Desorption
T0222 Earth Purification Engineering, Inc., Soil Cleanup System (SCS)
T0223 Earth Tech Bioremediation—Solid Phase
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0228 ECO-TEC, Inc., EnviroMech Gold Biocatalytic Contaminant Degradation
T0231 EFX Systems, Inc., Granular Activated Carbon-Fluidized Bed Reactor (GAC FBR) Process
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0256 Ensite, Inc., SafeSoil
T0257 EnSolve Biosystems, Inc., EnCell Bioreactor
T0259 ENSR International Group, Biovault
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE

T0277 Environmental Remediation Consultants, Inc., Biointegration
T0278 Environmental Remediation International (EnRem), Ltd., Soil Remediation System (SRS)
T0281 Environmental Resources Management Corporation (ERM), Advanced Fluidized Composting (AFC)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0289 EnviroSep, Inc., Thick-Film Absorption (TFA)
T0290 Enviro-Soil Remediation, Inc., Thermal Stripping
T0292 EnviroWall, Inc., EnviroWall Barrier
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0295 EOD Technology, Inc., Biotechnical Processing of Explosives
T0299 ETG Environmental, Inc., Thermo-O-Detox Medium Temperature Thermal Desorption (MTTD)
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0309 Fixed Bed Soil Biofilters—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0323 G.E.M., Inc., Chemical Treatment
T0329 General Atomics, Supercritical Water Oxidation
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0344 Geosafe Corporation, In Situ Vitrification
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0348 GHEA Associates, Soil Washing Technology
T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0355 Granular Activated Carbon (GAC)—General
T0356 Groundwater Recovery Systems, Inc., OXY 1
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume-Interception Treatment Technology
T0369 Heaven from Earth, Inc., Organic Cleaners
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process In Situ
T0380 Hrubetz Environmental Services, Inc., HRUBOUT Process, Ex Situ
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0388 Hydrogen Peroxide In Situ Bioremediation—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0405 In Situ Oil Skimmers—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC

T0412 Institute of Gas Technology, MGP-REM
T0416 Intech One Eighty, White-Rot Fungus
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0423 InterBio, Phenobac
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0434 IT Corporation, Biological Polishing Treatment
T0438 IT Corporation, Enhanced Natural Degradation (END)
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0449 IT Corporation, Thermal Desorption
T0452 Joule-Heated Vitrification—General
T0454 KAL CON Environmental Services, Thermal Desorption
T0457 KEMRON Environmental Services, Inc., Bioremediation—Soil and Groundwater
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0459 King, Buck Technologies, Inc., HD CatOx System
T0460 King, Buck Technologies, Inc., MultiMode Combustion
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0476 Lehigh University, Ground Rubber as a Reactive Permeable Barrier Sorption Media
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0489 M.L. Chartier, Inc., The Therminator
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0495 Maple Engineering Services, Inc., Biopur
T0496 MARCOR Remediation, Inc., Advanced Chemical Treatment
T0497 Massachusetts Institute of Technology, Tunable Hybrid Plasma
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0500 Maxymillian Technologies, Inc., Thermal Desorption System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0503 Media and Process Technology, Inc., Bioscrubber
T0504 Medina Agricultural Products Company, Inc., Medina Bioremediation Products
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0511 Metals Removal Via Peat—General
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc., (MATS) Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0530 MIOX Corporation, Miox System
T0532 Modified Natural Clays—General
T0535 Molten Metal Technology, Inc., Quantum Catalytic Extraction Process (Q-CEP)
T0541 MYCELX Technologies Corporation, MYCELX
T0546 Natural Attenuation—General

T0547 NEPCCO Environmental Systems, SoilPurge
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0555 Niaski Environmental, Inc., Biopurge
T0556 Niaski Environmental, Inc., BioSparge System
T0561 North American Drilling Technologies (NADT), Inc., EnviroZyme
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0566 NUCON International, Inc., Brayton Cycle
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0573 O'Brien & Gere Engineers, Inc., Mechanical Volatilization Screening
T0577 On-Site Technologies, Modular Interchangeable Treatment System (MITS)
T0578 OnSite Technology, L.L.C., Portable Indirect Thermal Desorption (ITD)
T0579 On-Site Thermal Services Division of Soil Restoration and Recycling, L.L.C., Low-Temperature Thermal Desorption Plant
T0584 Osprey Biotechnics, Munox
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0592 Passive Soil Vapor Extraction—General
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
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T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0610 Pile Biodegradation (Biopile), Multiple Vendors
T0613 Plasma Vitrification—General
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T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0656 Remtech Engineers, Bubble Lance Low-Profile Diffused Air Stripper
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0661 Reverse Osmosis—General
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0668 Rochem Environmental, Inc., Disc Tube

T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0672 Rohm and Haas Company, Ambersorb 600
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0676 Rusmar, Inc., Long-Duration Foam
T0680 S.S. Papadopulos & Associates, Inc., DeNAPLs (Detergent Extraction of NAPLs)
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0732 Solvent Extraction—General
T0733 Sonotech, Inc., Cello Pulse Combustion BurnerSystem
T0735 Sound Remedial Technologies, Inc., Hot Air Vapor Extraction (HAVE)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0750 Stevens Institute of Technology, Trench Bio-Sparge
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0759 Surfactants—General
T0761 Sybron Chemicals, Inc., ABR (Augmented Bioreclamation) Microbial Blends
T0764 Tarmac Environmental Company, Inc., Thermal Desorption
T0768 Tekno Associates, Biolift
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0771 Terra Vac, DNAPL Vaporization
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0792 The Westford Chemical Corporation, BioSolv
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)

T0802 ThermoRetec, Microbial Fence
T0805 ThermoRetec, Thermatek Thermal Desorption
T0807 Thorneco, Inc., Enzyme-Activated Cellulose Technology
T0811 TPS Technologies, Inc., Thermal Desorption
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0817 T-Thermal Company, Submerged Quench Incineration
T0820 U.S. Environmental Protection Agency, Reductive Anaerobic Biological In Situ Treatment (RABIT)
T0823 U.S. Filter Corporation, PO*WW*ER Wastewater Treatment System
T0825 U.S. Filter, Ultrox Peroxone Oxidation
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0835 Umpqua Research Company, Low-Temperature Aqueous Phase Catalytic Oxidation
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0847 University of New South Wales, Upflow Washing
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0863 W.E.S., Inc., Microb-Sparging
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0870 Waste Stream Technology, Inc., Bioremediation
T0871 WASTECH, Inc., Solidification and Stabilization
T0873 Water Equipment Services, Inc., Environmental Division Vacu-Point
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0884 Westinghouse Savannah River Company, In Situ Bioremediation of Chlorinated Solvents with Natural Gas
T0889 White Rot Fungus—General
T0890 WIK Associates, Inc., Bugs+Plus
T0891 Williams Environmental, RamSorb-1
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0899 Zenon Environmental Systems, Inc., ZenoGem
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Biphenyl

T0011 Advanced Microbial Solutions, SuperBio
T0126 Bioventing—General
T0135 Calgon Carbon Corporation, Activated Carbon
T0178 Constructed Wetlands—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0320 Funderburk & Associates, Solidification Process
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation

T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0759 Surfactants—General

Cumene; Isopropyl Benzene; Methylethyl Benzene

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads

Ethylbenzene

T0011 Advanced Microbial Solutions, SuperBio
T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0067 Ariel Industries, Inc., Ariel SST Low-Temperature Thermal Desorber
T0068 Armstrong Laboratory Environics Directorate, Phase-Transfer Oxidation
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0093 Bio Solutions, Inc., Soil Slurry—Sequencing Batch Reactor
T0096 BioEnviroTech, Inc., BioPetro
T0098 BioGee International, Inc., BioGee HC
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0105 Biogenie, Inc., Biogenie Biopile
T0108 Biomin, Inc., Organoclay
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0117 Bioslurping—General
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0123 BioTrol Inc., Biological Aqueous Treatment System
T0126 Bioventing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0129 Bogart Environmental Services, Inc., MiKIE
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0136 Calgon Carbon Corporation Technologies, Rayox
T0137 Calgon Carbon Corporation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0142 Carlo Environmental Technologies, Inc., Medium Temperature Thermal Desorption (MTTD)
T0143 Carson Environmental, Low-Temperature Oxidation
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0158 CH2M Hill, Phytoremediation-Based Systems

T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0164 ChemPete, Inc., Bioremediation
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0168 CleanSoil, Inc., CleanSoil Process
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0177 Conor Pacific, WINDsparge
T0178 Constructed Wetlands—General
T0182 ConTeck Environmental Services, Inc., Soil Roaster
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0197 Dames and Moore, Two-Phase Vacuum Extraction
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0201 Delta Cooling Towers, Inc., Aqua-Trim and Vanguard Air Strippers
T0202 Detox Industries, Inc., DETOX Process
T0208 Donald L. Geisel & Associates, Inc., HeatTrode Thermally Accelerated In Situ Bioremediation
T0212 Dual Phase Extraction—General
T0215 DuraTherm, Inc., DuraTherm Desorption
T0222 Earth Purification Engineering, Inc., Soil Cleanup System (SCS)
T0223 Earth Tech, Bioremediation—Solid Phase
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0228 ECO-TEC, Inc., EnviroMech Gold Biocatalytic Contaminant Degradation
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized Bed Reactor (GAC FBR) Process
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0256 Ensite, Inc., SafeSoil
T0257 EnSolve Biosystems, Inc., EnCell Bioreactor
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0278 Environmental Remediation International (EnRem), Ltd., Soil Remediation System (SRS)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0290 Enviro-Soil Remediation, Inc., Thermal Stripping
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0295 EOD Technology, Inc., Biotechnical Processing of Explosives
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0309 Fixed-Bed Soil Biofilters—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0344 Geosafe Corporation, In Situ Vitrification

T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0355 Granular Activated Carbon (GAC)—General
T0356 Groundwater Recovery Systems, Inc., OXY 1
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume-Interception Treatment Technology
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process, In Situ
T0380 Hrubetz Environmental Services, Inc., HRUBOUT Process, Ex Situ
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0388 Hydrogen Peroxide In Situ Bioremediation—General
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0405 In Situ Oil Skimmers—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0412 Institute of Gas Technology, MGP-REM
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0434 IT Corporation, Biological Polishing Treatment
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0454 KAL CON Environmental Services, Thermal Desorption
T0457 KEMRON Environmental Services, Inc., Bioremediation—Soil and Groundwater
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0459 King, Buck Technologies, Inc., HD CatOx System
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0489 M.L. Chartier, Inc., Therminator
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0495 Maple Engineering Services, Inc., Biopur
T0496 MARCOR Remediation, Inc., Advanced Chemical Treatment
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0500 Maxymillian Technologies, Inc., Thermal Desorption System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0504 Medina Agricultural Products Company, Inc., Medina Bioremediation Products
T0506 Membran Corporation, Membrane Gas Transfer

T0509 Metal-Based Permeable Reactive Barriers—General
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0530 MIOX Corporation, Miox System
T0541 MYCELX Technologies Corporation, MYCELX
T0546 Natural Attenuation—General
T0547 NEPCCO Environmental Systems, SoilPurge
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0555 Niaski Environmental, Inc., Biopurge
T0556 Niaski Environmental, Inc., BioSparge System
T0561 North American Drilling Technologies (NADT), Inc., EnviroZyme
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0573 O'Brien & Gere Engineers, Inc., Mechanical Volatilization Screening
T0577 On-Site Technologies, Modular Interchangeable Treatment System (MITS)
T0578 OnSite Technology, L.L.C., Portable Indirect Thermal Desorption (ITD)
T0584 Osprey Biotechnics, Munox
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0592 Passive Soil Vapor Extraction—General
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0602 Pet-Con Soil Remediation, Inc., Thermal Desorption
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0610 Pile Biodegradation (Biopile), Multiple Vendors
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0626 Product Services Company, Oil Gator
T0628 PTC Enterprises, BioTreat System
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0638 R.E. Wright Environmental, Inc., Steam-Enhanced Recovery
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0656 Remtech Engineers, Bubble Lance Low-Profile Diffused Air Stripper
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0661 Reverse Osmosis—General
T0668 Rochem Environmental, Inc., Disc Tube
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0676 Rusmar, Inc., Long-Duration Foam

T0680 S.S. Papadopulos & Associates, Inc., DeNAPLs (Detergent Extraction of NAPLs)
T0689 SBP Technologies, Inc., Membrane Filtration
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0732 Solvent Extraction—General
T0733 Sonotech, Inc., Cello Pulse Combustion BurnerSystem
T0735 Sound Remedial Technologies, Inc., Hot Air Vapor Extraction (HAVE)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0750 Stevens Institute of Technology, Trench Bio-Sparge
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0759 Surfactants—General
T0761 Sybron Chemicals, Inc., ABR (Augmented Bioreclamation) Microbial Blends
T0764 Tarmac Environmental Company, Inc., Thermal Desorption
T0768 Tekno Associates, Biolift
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0792 The Westford Chemical Corporation, BioSolv
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0802 ThermoRetec, Microbial Fence
T0805 ThermoRetec, Thermatek Thermal Desorption
T0811 TPS Technologies, Inc., Thermal Desorption
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0845 University of Dayton, Research Institute Photothermal Detoxification Unit
T0847 University of New South Wales, Upflow Washing
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General

T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0871 WASTECH, Inc., Solidification and Stabilization
T0873 Water Equipment Services, Inc., Environmental Division Vacu-Point
T0890 WIK Associates, Inc., Bugs+Plus
T0891 Williams Environmental, RamSorb-1
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0899 Zenon Environmental Systems, Inc., ZenoGem
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Styrene

T0011 Advanced Microbial Solutions, SuperBio
T0033 Ambient Engineering, Inc., BIOTON
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0129 Bogart Environmental Services, Inc., MiKIE
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0168 CleanSoil, Inc., CleanSoil Process
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0289 EnviroSep, Inc., Thick-Film Absorption (TFA)
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0355 Granular Activated Carbon (GAC)—General
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0535 Molten Metal Technology, Inc., Quantum Catalytic Extraction Process (Q-CEP)
T0546 Natural Attenuation—General
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0610 Pile Biodegradation (Biopile), Multiple Vendors
T0617 PPC Biofilter, Biofiltration Systems
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0689 SBP Technologies, Inc., Membrane Filtration
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0805 ThermoRetec, Thermatek Thermal Desorption
T0855 Vapor-Phase Biofiltration—General
T0899 Zenon Environmental Systems, Inc., ZenoGem

Toluene

T0011 Advanced Microbial Solutions, SuperBio
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0033 Ambient Engineering, Inc., BIOTON
T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0041 AP Technologies, Inc., Mercrobes Mercury Reduction Technology
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
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T0105 Biogenie, Inc., Biogenie Biopile
T0106 Biological Activated Carbon—General
T0108 Biomin, Inc., Organoclay
T0113 Bioremediation Service, Inc., AquaPlant Biofilter System
T0114 Bioremediation Technology Services, Inc., BTS Method
T0115 Bioscience, Inc., BIOX Biotreater
T0117 Bioslurping—General
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0122 Biotrickling Filter—General
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0129 Bogart Environmental Services, Inc., MiKIE
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T0137 Calgon Carbon Oxidation Technologies, Solaqua
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T0227 Ecolotree, Inc., Ecolotree Cap
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T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0256 Ensite, Inc., SafeSoil
T0257 EnSolve Biosystems, Inc., EnCell Bioreactor
T0259 ENSR International Group, Biovault
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0278 Environmental Remediation International (EnRem), Ltd., Soil Remediation System (SRS)
T0281 Environmental Resources Management Corporation (ERM), Advanced Fluidized Composting (AFC)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0289 EnviroSep, Inc., Thick-Film Absorption (TFA)
T0290 Enviro-Soil Remediation, Inc., Thermal Stripping
T0292 EnviroWall, Inc., EnviroWall Barrier
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)

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T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0323 G.E.M., Inc., Chemical Treatment
T0329 General Atomics, Supercritical Water Oxidation
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0344 Geosafe Corporation, In Situ Vitrification
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0348 GHEA Associates, Soil Washing Technology
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T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume-Interception Treatment Technology
T0369 Heaven from Earth, Inc., Organic Cleaners
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process, In Situ
T0380 Hrubetz Environmental Services, Inc., HRUBOUT Process, Ex Situ
T0384 Hydraulic Fracturing—General
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0388 Hydrogen Peroxide In Situ Bioremediation—General
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T0405 In Situ Oil Skimmers—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0412 Institute of Gas Technology, MGP-REM
T0416 Intech One Eighty, White-Rot Fungus
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0434 IT Corporation, Biological Polishing Treatment
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0449 IT Corporation, Thermal Desorption
T0452 Joule-Heated Vitrification—General
T0454 KAL CON Environmental Services, Thermal Desorption
T0457 KEMRON Environmental Services, Inc., Bioremediation—Soil and Groundwater
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0459 King, Buck Technologies, Inc., HD CatOx System
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA

T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0489 M.L. Chartier, Inc., Therminator
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0495 Maple Engineering Services, Inc., Biopur
T0496 MARCOR Remediation, Inc., Advanced Chemical Treatment
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
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T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0503 Media and Process Technology, Inc., Bioscrubber
T0504 Medina Agricultural Products Company, Inc., Medina Bioremediation Products
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0530 MIOX Corporation, Miox System
T0532 Modified Natural Clays—General
T0541 MYCELX Technologies Corporation, MYCELX
T0546 Natural Attenuation—General
T0547 NEPCCO Environmental Systems, SoilPurge
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0555 Niaski Environmental, Inc., Biopurge
T0556 Niaski Environmental, Inc., BioSparge System
T0561 North American Drilling Technologies (NADT), Inc., EnviroZyme
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0566 NUCON International, Inc., Brayton Cycle
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0573 O'Brien & Gere Engineers, Inc., Mechanical Volatilization Screening
T0577 On-Site Technologies, Modular Interchangeable Treatment System (MITS)
T0578 OnSite Technology, L.L.C., Portable Indirect Thermal Desorption (ITD)
T0579 On-Site Thermal Services, Division of Soil Restoration and Recycling, L.L.C., Low-Temperature Thermal Desorption Plant
T0584 Osprey Biotechnics, Munox
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0592 Passive Soil Vapor Extraction—General
T0595 Peat/Compost Biofiltration—General
T0596 Pecan-Based Granular Activated Carbon—General
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General

T0602 Pet-Con Soil Remediation, Inc., Thermal Desorption
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically-Engineered Plants
T0610 Pile Biodegradation (Biopile), Multiple Vendors
T0613 Plasma Vitrification—General
T0617 PPC Biofilter, Biofiltration Systems
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0626 Product Services Company, Oil Gator
T0628 PTC Enterprises, BioTreat System
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0638 R.E. Wright Environmental, Inc., Steam Enhanced Recovery
T0639 R.E. Wright Environmental, Inc., In Situ Bioremediation Treatment System
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0656 Remtech Engineers, Bubble Lance Low-Profile Diffused Air Stripper
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0661 Reverse Osmosis—General
T0668 Rochem Environmental, Inc., Disc Tube
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0672 Rohm and Haas Company, Ambersorb 600
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0676 Rusmar, Inc., Long-Duration Foam
T0680 S.S. Papadopulos & Associates, Inc., DeNAPLs (Detergent Extraction of NAPLs)
T0689 SBP Technologies, Inc., Membrane Filtration
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0732 Solvent Extraction—General
T0733 Sonotech, Inc., Cello Pulse Combustion BurnerSystem
T0735 Sound Remedial Technologies, Inc., Hot Air Vapor Extraction (HAVE)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0750 Stevens Institute of Technology, Trench Bio-Sparge
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0756 Supercritical Water Oxidation—General
T0759 Surfactants—General

T0761 Sybron Chemicals, Inc., ABR (Augmented Bioreclamation) Microbial Blends
T0764 Tarmac Environmental Company, Inc., Thermal Desorption
T0768 Tekno Associates, Biolift
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0792 The Westford Chemical Corporation, BioSolv
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0802 ThermoRetec, Microbial Fence
T0805 ThermoRetec, Thermatek Thermal Desorption
T0811 TPS Technologies, Inc., Thermal Desorption
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0820 U.S. Environmental Protection Agency, Reductive Anaerobic Biological In Situ Treatment (RABIT)
T0823 U.S. Filter Corporation, PO*WW*ER Wastewater Treatment System
T0825 U.S. Filter, Ultrox Peroxone Oxidation
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0847 University of New South Wales, Upflow Washing
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0870 Waste Stream Technology, Inc., Bioremediation
T0871 WASTECH, Inc., Solidification and Stabilization
T0873 Water Equipment Services, Inc., Environmental Division Vacu-Point
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0884 Westinghouse Savannah River Company, In Situ Bioremediation of Chlorinated Solvents with Natural Gas
T0889 White-Rot Fungus—General
T0890 WIK Associates, Inc., Bugs+Plus
T0891 Williams Environmental, RamSorb-1
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0899 Zenon Environmental Systems, Inc., ZenoGem
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

BENZENE AND SUBSTITUTED BENZENE HYDROCARBONS

T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0108 Biomin, Inc., Organoclay
T0135 Calgon Carbon Corporation, Activated Carbon
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0193 Current Environmental Solutions, L.L.C., In Situ Corona
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0267 Envirogen, Inc., Spartech
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0541 MYCELX Technologies Corporation, MYCELX
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0676 Rusmar, Inc., Long-Duration Foam
T0689 SBP Technologies, Inc., Membrane Filtration
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0755 Supercritical Carbon Dioxide Extraction—General
T0779 Terra Vac, Inc., Vacuum Extraction

BENZENE, TOLUENE, ETHYLBENZENE, AND XYLENE (BTEX)

T0011 Advanced Microbial Solutions, SuperBio
T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0067 Ariel Industries, Inc., Ariel SST Low-Temperature Thermal Desorber
T0068 Armstrong Laboratory Environics Directorate, Phase-Transfer Oxidation
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0093 Bio Solutions, Inc., Soil Slurry—Sequencing Batch Reactor
T0096 BioEnviroTech, Inc., BioPetro

T0098 BioGee International, Inc., BioGee HC
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0105 Biogenie, Inc., Biogenie Biopile
T0108 Biomin, Inc., Organoclay
T0117 Bioslurping—General
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0142 Carlo Environmental Technologies, Inc., Medium Temperature Thermal Desorption (MTTD)
T0143 Carson Environmental, Low-Temperature Oxidation
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0158 CH2M Hill, Phytoremediation-Based Systems
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0164 ChemPete, Inc., Bioremediation
T0168 CleanSoil, Inc., CleanSoil Process
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0177 Conor Pacific, WINDsparge
T0178 Constructed Wetlands—General
T0182 ConTeck Environmental Services, Inc., Soil Roaster
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0195 DAHL & Associates, Inc., ThermNet
T0197 Dames and Moore, Two-Phase Vacuum Extraction
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0201 Delta Cooling Towers, Inc., Aqua-Trim and Vanguard Air Strippers
T0202 Detox Industries, Inc., DETOX Process
T0208 Donald L. Geisel & Associates, Inc., HeatTrode Thermally Accelerated In Situ Bioremediation
T0211 DRL Environmental Services, Enco-Tec RS-30 Thermal Desorption
T0212 Dual-Phase Extraction—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0222 Earth Purification Engineering, Inc., Soil Cleanup System (SCS)
T0223 Earth Tech, Bioremediation—Solid Phase
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap

T0228 ECO-TEC, Inc., EnviroMech Gold Biocatalytic Contaminant Degradation
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized Bed Reactor (GAC FBR) Process
T0233 Ejector Systems, Inc., VESTRIP
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0256 Ensite, Inc., SafeSoil
T0257 EnSolve Biosystems, Inc., EnCell Bioreactor
T0260 ENSR International Group, Soil Cleaning Process
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0278 Environmental Remediation International (EnRem), Ltd., Soil Remediation System (SRS)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0290 Enviro-Soil Remediation, Inc., Thermal Stripping
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0295 EOD Technology, Inc., Biotechnical Processing of Explosives
T0300 ETUS, Inc., Enhanced Bioremediation
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0309 Fixed-Bed Soil Biofilters—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0344 Geosafe Corporation, In Situ Vitrification
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0355 Granular Activated Carbon (GAC)—General
T0356 Groundwater Recovery Systems, Inc., OXY 1
T0360 H&H Eco Systems, Inc., Microenfractionator
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0364 Harding ESE, Inc., Bioremediation—Landfarming Treatment
T0365 Harding ESE, Inc., Composting
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume-Interception Treatment Technology
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0373 Horizontal Drilling—General
T0374 Horizontal Technologies, Inc., Linear Containment Remediation System
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process, In Situ
T0380 Hrubetz Environmental Services, Inc., HRUBOUT Process, Ex Situ
T0384 Hydraulic Fracturing—General
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0388 Hydrogen Peroxide In Situ Bioremediation—General
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0399 IEG Technologies, Groundwater Circulation Wells (GZB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads

T0405 In Situ Oil Skimmers—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0412 Institute of Gas Technology, MGP-REM
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0434 IT Corporation, Biological Polishing Treatment
T0437 IT Corporation, Engineered Bioremediation System
T0438 IT Corporation, Enhanced Natural Degradation (END)
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry Phase Bioremediation—Full Scale
T0454 KAL CON Environmental Services, Thermal Desorption
T0457 KEMRON Environmental Services, Inc., Bioremediation—Soil and Groundwater
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0459 King, Buck Technologies, Inc., HD CatOx System
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0476 Lehigh University, Ground Rubber as a Reactive Permeable Barrier Sorption Media
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0489 M.L. Chartier, Inc., Therminator
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0495 Maple Engineering Services, Inc., Biopur
T0496 MARCOR Remediation, Inc., Advanced Chemical Treatment
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0500 Maxymillian Technologies, Inc., Thermal Desorption System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
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T0595 Peat/Compost Biofiltration—General
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T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
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T0628 PTC Enterprises, BioTreat System
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0638 R.E. Wright Environmental, Inc., Steam Enhanced Recovery
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T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0656 Remtech Engineers, Bubble Lance Low-Profile Diffused Air Stripper
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0676 Rusmar, Inc., Long-Duration Foam
T0680 S.S. Papadopulos & Associates, Inc., DeNAPLs (Detergent Extraction of NAPLs)
T0689 SBP Technologies, Inc., Membrane Filtration
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0732 Solvent Extraction—General
T0733 Sonotech, Inc., Cello Pulse Combustion BurnerSystem
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc. Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)

T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0750 Stevens Institute of Technology, Trench Bio-Sparge
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0759 Surfactants—General
T0761 Sybron Chemicals, Inc., ABR (Augmented Bioreclamation) Microbial Blends
T0764 Tarmac Environmental Company, Inc., Thermal Desorption
T0768 Tekno Associates, Biolift
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0792 The Westford Chemical Corporation, BioSolv
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0802 ThermoRetec, Microbial Fence
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0811 TPS Technologies, Inc., Thermal Desorption
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0847 University of New South Wales, Upflow Washing
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0873 Water Equipment Services, Inc., Environmental Division Vacu-Point
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General
T0890 WIK Associates, Inc., Bugs+Plus
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0893 WRS Infrastructure & Environmental, Inc., Thermal Desorption Unit
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0899 Zenon Environmental Systems, Inc., ZenoGem
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

BERYLLIUM

T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0054 Arctech, Inc., Humasorb
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0200 Delphi Research, Inc., DETOX
T0291 EnviroSource Technologies, Inc., Super Detox Process
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0510 Metals Recovery, Inc., Metals Leaching
T0540 MSE Technology Applications, Inc., Viscous Barrier Technology
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0817 T-Thermal Company, Submerged Quench Incineration
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)

BISMUTH

T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0582 Onyx Industrial Services, SOIL*EX
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0830 U.S. Naval Academy, Air Classifier with Removal of Metals from Soil

BROMIDE ION

T0329 General Atomics, Supercritical Water Oxidation
T0756 Supercritical Water Oxidation—General
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0817 T-Thermal Company, Submerged Quench Incineration

CADMIUM

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0015 Advanced Recovery Systems, Inc., DeHg
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0042 Applied Environmental Services, Inc., Asphaltic Metals Stabilization
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses

T0054 Arctech, Inc., Humasorb
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0080 Battelle Memorial Institute, Electroacoustic Dewatering
T0081 Battelle Memorial Institute, Liquid–Liquid Extraction of Metals (LLX)
T0090 Beco Engineering Company, Alka/Sorb
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0107 Biomet Mining Solutions Corporation, Biosulfide Process
T0118 Biosorption—General
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0149 Cement-Based Stabilization/Solidification—General
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0162 Chemical Precipitation of Metals—General
T0169 Clemson University, Sintered Ceramic Stabilization
T0176 Concurrent Technologies Corporation, Acid Extraction Treatment System (AETS)
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0200 Delphi Research, Inc., DETOX
T0207 Doe Run Company, TERRAMET Heavy Metal Removal Technology
T0214 DuPont/Oberlin, Microfiltration Technology
T0218 Dynaphore, Inc., Forager Sponge Technology
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0230 EET Corporation, Microwaste Waste Solidification
T0232 Eichrom Industries, Inc., Diphonix
T0235 Electrochemical Treatment of Contaminated Groundwater—General
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0262 Envirocare of Utah, Inc., Polyethylene Encapsulation
T0279 Environmental Research and Development, Inc., Neutral Process for Heavy-Metals Removal
T0280 Environmental Research and Development, Inc., Ice Electrode
T0291 EnviroSource Technologies, Inc., Super Detox Process
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0301 Evaporation for Wastewater Treatment—General
T0306 Ferro Corporation, Waste Vitrification Through Electric Melting
T0307 Filter Flow Technology, Inc., Colloid Polishing Filter Method
T0313 Forrester Environmental Services, Inc., Heavy-Metal Stabilization
T0320 Funderburk & Associates, Solidification Process
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0343 Georgia Institute of Technology, Construction Research Center In Situ Plasma Vitrification

T0344 Geosafe Corporation, In Situ Vitrification
T0355 Granular Activated Carbon (GAC)—General
T0359 GTS Duratek, DuraMelter
T0377 Horsehead Resource Development Company, Inc., Flame Reactor
T0378 HPT Research, Inc., Ionic State Modification (ISM) Process for the Treatment of Acid Mine Drainage
T0382 Humboldt State University, Chitosan Derivative
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0426 International Environmental Trading Company, Inc., Metals Extraction and Recycling System
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0443 IT Corporation, In Situ Geochemical Fixation
T0450 IT Corporation, Thermal Destruction Unit
T0452 Joule-Heated Vitrification—General
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0477 Lehigh University, Hybrid Inorganic Solvent HISORB
T0478 Lewis Environmental Services, Inc., Soil Leaching and Enviro-Clean Technologies
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0488 Lynntech, Inc., Electrokinetic Remediation of Contaminated Soil
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0510 Metals Recovery, Inc., Metals Leaching
T0511 Metals Removal Via Peat—General
T0517 Metcalf & Eddy, Inc., SOLFIX
T0518 Met-Chem, Metal Kleen A
T0519 Met-Chem, Metal Kleen B (MCB)
T0521 Met-Tech, Inc., Metal Separation by Liquid Ion Exchange
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0529 Millgard Corporation, MecTool Remediation System
T0533 Molasses Treatment for Bioremediation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0562 North American Technologies Group, Inc., System IV
T0583 Oregon State University, Chitosan Beads
T0588 Pacific Northwest National Laboratory, Self Assembled Mesoporous Support (SAMMS) Technology
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0594 PEAT, Inc., Thermal Destruction and Recovery
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0608 Phytoremediation—Hyperaccumulation—General
T0611 Pintail Systems, Inc., Spent Ore Bioremediation Process
T0613 Plasma Vitrification—General
T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System
T0615 Polymer-Based Solidification/Stabilization—General

T0616 Pozzolanic Solidification/Stabilization—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0624 Proactive Applied Solutions Corporation, LEADX
T0644 Recra Environmental, Inc., Alternating Current Electrocoagulation
T0657 Resonant Shock Compaction, L.L.C., Resonant Shock Compaction
T0658 Resource Management and Recovery, AlgaSORB
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0667 RMT, Inc., Metal Treatment Technology (MTTTM)
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0692 SCC Environmental, Micro-Flo
T0696 Science Applications International Corporation, Plasma Hearth Process
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0726 Solidification/Stabilization—General
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0730 Solucorp Industries, Ltd., Molecular Bonding System
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0741 Stark Encapsulation, Inc., METLCAP Chemical Cement
T0742 Starmet Corporation, RocTec Stabilization
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0763 Tallon, Inc., Virtokele
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0772 Terra Vac, Geochemical Fixation
T0787 Texaco, Inc., Texaco Gasification Process
T0789 Texilla Environmental, Inc., Synthetic Mineral Immobilization Technology (SMITE)
T0799 ThermoChem, Inc., PulseEnhanced Steam Reformer
T0801 Thermoplastic Stabilization/Solidification—General
T0808 Toledo Engineering Co., Inc., High-Temperature Joule-Heated Vitrification
T0810 Toxic Environmental Control Systems, Inc., Electrode-Assisted Soil Washing
T0815 Trigon Group, L.L.C., ARCHON In Situ Mixer
T0818 TVIES, Inc., Soil Washing
T0821 U.S. EPA and IT Corporation, Debris Washing System
T0824 U.S. Filter Corporation, WESPHix
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0849 University of Washington, Metals Treatment by Adsorptive Filtration
T0850 UOP, Inc., Ionsiv IE-911 Ion Exchange Resins
T0862 Vortec Corporation, Cyclone Melting System (CMS)
T0874 Water Technology International Corporation, Self-Sealing/Self-Healing Barrier (SS/SH)
T0880 Western Product Recovery Group, Inc., Coordinate Chemical Bonding and Adsorption (CCBA) Process
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0899 Zenon Environmental Systems, Inc., ZenoGem

CALCIUM

T0001 3M Company, 3M Empore Extraction Disk
T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0158 CH2M Hill, Phytoremediation-based Systems
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0230 EET Corporation, Microwaste Waste Solidification
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0355 Granular Activated Carbon (GAC)—General
T0378 HPT Research, Inc., Ionic State Modification (ISM) Process for the Treatment of Acid Mine Drainage
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0596 Pecan-Based Granular Activated Carbon—General
T0607 Phytoremediation—General
T0613 Plasma Vitrification—General
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0808 Toledo Engineering Co., Inc., High-Temperature Joule-Heated Vitrification

CARBON COMPOUNDS

Carbon Compounds

T0459 King, Buck Technologies, Inc., HD CatOx System
T0467 KSE, Inc., AIR-II Process
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

Carbon Monoxide

T0459 King, Buck Technologies, Inc., HD CatOx System
T0467 KSE, Inc., AIR-II Process
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

CARBOXYLIC ACIDS

Acetic Acid

T0138 Calgon Carbon Corporation, Perox-Pure
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)

T0185 Corrpro Companies Inc., Electroremediation
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0281 Environmental Resources Management Corporation (ERM), Advanced Fluidized Composting (AFC)
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0756 Supercritical Water Oxidation—General
T0877 Weatherly, Inc., AQUA CRITOX (R)

Acrylic Acid; Propenoic Acid

T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0355 Granular Activated Carbon (GAC)—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

Benzoic Acid

T0087 Battelle Pacific Northwest National Laboratory, Liquid Corona
T0135 Calgon Carbon Corporation, Activated Carbon
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0355 Granular Activated Carbon (GAC)—General
T0365 Harding ESE, Inc., Composting
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0775 Terra Vac, Inc., Dual Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)

Carboxylic Acids

T0087 Battelle Pacific Northwest National Laboratory, Liquid Corona
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0178 Constructed Wetlands—General
T0185 Corrpro Companies Inc., Electroremediation
T0223 Earth Tech, Bioremediation—Solid Phase
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning

T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0281 Environmental Resources Management Corporation (ERM), Advanced Fluidized Composting (AFC)
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0355 Granular Activated Carbon (GAC)—General
T0365 Harding ESE, Inc., Composting
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0541 MYCELX Technologies Corporation, MYCELX
T0637 R.C. Costello and Associates, Inc., Actopentin Biomass Filter
T0756 Supercritical Water Oxidation—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0877 Weatherly, Inc., AQUA CRITOX (R)

CARBOXYLIC ACIDS AND DERIVATIVES

T0168 CleanSoil, Inc., CleanSoil Process
T0406 In Situ soil Vapor Extraction (SVE)—General
T0541 MYCELX Technologies Corporation, MYCELX

CARBOXYLIC ACIDS WITH OTHER FUNCTIONAL GROUPS

Carboxylic Acids with Other Functional Groups

T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0178 Constructed Wetlands—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0320 Funderburk & Associates, Solidification Process
T0325 Galson Remediation Corporation, APEG-PLUS Process
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General

Dichlorophenoxyacetic Acid; 2,4-D

T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General

T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0320 Funderburk & Associates, Solidification Process
T0325 Galson Remediation Corporation, APEG-PLUS Process
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General

CESIUM

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0054 Arctech, Inc., Humasorb
T0058 Arctic Foundations, Inc., Cryogenic Barrier
T0059 Argonne National Laboratory, Advanced Integrated Solvent Extraction and Ion Exchange Systems
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0064 Argonne National Laboratory, Magnetically Assisted Chemical Separation (MACS)
T0072 Atomic Energy of Canada Ltd. (AECL), CHEMIC Technology
T0083 Battelle Pacific Northwest Laboratory, Compact Processing Unit (CPU)
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0134 CAE Alpheus, Inc., Carbon Dioxide Blasting
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0174 Commodore Separation Technologies, Inc., Supported Liquid Membrane
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0232 Eichrom Industries, Inc., Diphonix
T0236 Electrokinetic Remediation—General
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0344 Geosafe Corporation, In Situ Vitrification
T0355 Granular Activated Carbon (GAC)—General
T0359 GTS Duratek, DuraMelter
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0452 Joule-Heated Vitrification—General
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0529 Millgard Corporation, MecTool Remediation System
T0531 Mirage Systems, Inc., ChemChar Process
T0535 Molten Metal Technology, Inc., Quantum Catalytic Extraction Process (Q-CEP)
T0536 Molten Salt Oxidation—General
T0546 Natural Attenuation—General
T0596 Pecan-Based Granular Activated Carbon—General
T0607 Phytoremediation—General

T0608 Phytoremediation—Hyperaccumulation—General
T0613 Plasma Vitrification—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0646 RedZone Robotics, Inc., Houdini
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0696 Science Applications International Corporation, Plasma Hearth Process
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0737 Spar Aerospace, Ltd., Light-Duty Utility Arm
T0752 Stir-Melter, Inc., Stir-Melter
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0798 Thermo Nuclean, Segmented Gate System (SGS)
T0799 ThermoChem, Inc., PulseEnhanced Steam Reformer
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0850 UOP, Inc., Ionsiv IE-911 Ion Exchange Resins
T0851 UOP, Inc., TIE-96 Ion Exchange Resins
T0862 Vortec Corporation, Cyclone Melting System (CMS)
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process

CHLORINE AND CHLORINE COMPOUNDS

T0355 Granular Activated Carbon (GAC)—General
T0359 GTS Duratek, DuraMelter
T0817 T-Thermal Company, Submerged Quench Incineration

CHLORINE COMPOUNDS

Chlorine Compounds

T0355 Granular Activated Carbon (GAC)—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

Chlorine Gas

T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

CHLORINE, IONIC SPECIES

Chlorides

T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0158 CH2M Hill, Phytoremediation-based Systems
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0236 Electrokinetic Remediation—General
T0329 General Atomics, Supercritical Water Oxidation
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0531 Mirage Systems, Inc., ChemChar Process

T0543 Naiad Technologies, Inc., RadAway
T0561 North American Drilling Technologies (NADT), Inc., EnviroZyme
T0607 Phytoremediation—General
T0661 Reverse Osmosis—General
T0668 Rochem Environmental, Inc., Disc Tube
T0756 Supercritical Water Oxidation—General
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0860 Viatec Recovery Systems, Inc., Waste Acid Detoxification and Reclamation

Chlorine, Ionic Species

T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0045 Applied Research Associates, Inc., Bioremediation of Perchlorate
T0158 CH2M Hill, Phytoremediation-based Systems
T0178 Constructed Wetlands—General
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0236 Electrokinetic Remediation—General
T0255 EnSafe, Inc., Bioremediation of Perchlorate
T0329 General Atomics, Supercritical Water Oxidation
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0466 Krudico, Inc., Ion Exchange Resins for Nitrate and Perchlorate
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0531 Mirage Systems, Inc., ChemChar Process
T0543 Naiad Technologies, Inc., RadAway
T0561 North American Drilling Technologies (NADT), Inc., EnviroZyme
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0607 Phytoremediation—General
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0653 Remediation of Perchlorate—General
T0661 Reverse Osmosis—General
T0668 Rochem Environmental, Inc., Disc Tube
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0756 Supercritical Water Oxidation—General
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0860 Viatec Recovery Systems, Inc., Waste Acid Detoxification and Reclamation

Perchlorates

T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0045 Applied Research Associates, Inc., Bioremediation of Perchlorate
T0178 Constructed Wetlands—General
T0255 EnSafe, Inc., Bioremediation of Perchlorate
T0329 General Atomics, Supercritical Water Oxidation
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process

T0466 Krudico, Inc., Ion Exchange Resins for Nitrate and Perchlorate
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0607 Phytoremediation—General
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0653 Remediation of Perchlorate—General
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0756 Supercritical Water Oxidation—General

CHROMIUM

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0023 Affinity Water Technologies, Advanced Affinity Chromatography
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0045 Applied Research Associates, Inc., Bioremediation of Perchlorate
T0050 Aquathermolysis—General
T0052 ARCADIS Geraghty and Miller, Inc., In Situ Reactive Zones Using Molasses
T0054 Arctech, Inc., Humasorb
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0064 Argonne National Laboratory, Magnetically Assisted Chemical Separation (MACS)
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0080 Battelle Memorial Institute, Electroacoustic Dewatering
T0081 Battelle Memorial Institute, Liquid–Liquid Extraction of Metals (LLX)
T0088 Battelle Pacific Northwest National Laboratory, Terra-VIT Vitrification Technology
T0090 Beco Engineering Company, Alka/Sorb
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0149 Cement-Based Stabilization/Solidification—General
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0158 CH2M Hill, Phytoremediation-Based Systems
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0162 Chemical Precipitation of Metals—General
T0169 Clemson University, Sintered Ceramic Stabilization
T0170 Clyde Engineering Service, Metals Removal
T0174 Commodore Separation Technologies, Inc., Supported Liquid Membrane
T0176 Concurrent Technologies Corporation, Acid Extraction Treatment System (AETS)

T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0185 Corrpro Companies, Inc., Electroremediation
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0200 Delphi Research, Inc., DETOX
T0207 Doe Run Company, TERRAMET Heavy-Metal Removal Technology
T0214 DuPont/Oberlin, Microfiltration Technology
T0218 Dynaphore, Inc., Forager Sponge Technology
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0230 EET Corporation, Microwaste Waste Solidification
T0232 Eichrom Industries, Inc., Diphonix
T0235 Electrochemical Treatment of Contaminated Groundwater—General
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0279 Environmental Research and Development, Inc., Neutral Process for Heavy-Metals Removal
T0280 Environmental Research and Development, Inc., Ice Electrode
T0285 Environmental Technology (U.S.), Inc., TR-Detox
T0291 EnviroSource Technologies, Inc., Super Detox Process
T0292 EnviroWall, Inc., EnviroWall Barrier
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0301 Evaporation for Wastewater Treatment—General
T0306 Ferro Corporation, Waste Vitrification through Electric Melting
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0313 Forrester Environmental Services, Inc., Heavy-Metal Stabilization
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0320 Funderburk & Associates, Solidification Process
T0322 G.E.M., Inc., Treatment of Chromated Copper Arsenate (CCA) in Wood Products
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0343 Georgia Institute of Technology, Construction Research Center In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0345 Geotech Development Corporation, Cold Top Ex Situ Vitrification Process
T0348 GHEA Associates, Soil Washing Technology
T0359 GTS Duratek, DuraMelter
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0410 Institute of Gas Technology, AGGCOM
T0416 Intech One Eighty, White-Rot Fungus
T0418 Integrated Chemistries, Inc., Metraxt
T0426 International Environmental Trading Company, Inc., Metals Extraction and Recycling System
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0443 IT Corporation, In Situ Geochemical Fixation
T0450 IT Corporation, Thermal Destruction Unit
T0452 Joule-Heated Vitrification—General
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1

T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0469 Kvaerner Metals, Resin-in-Pulp/Carbon-in-Pulp
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0478 Lewis Environmental Services, Inc., Soil-Leaching and Enviro-Clean Technologies
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0486 Los Alamos National Laboratory, Uranium Heap Leaching Technology
T0488 Lynntech, Inc., Electrokinetic Remediation of Contaminated Soil
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0496 MARCOR Remediation, Inc., Advanced Chemical Treatment
T0509 Metal-Based Permeable Reactive Barriers—General
T0510 Metals Recovery, Inc., Metals Leaching
T0511 Metals Removal via Peat—General
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0517 Metcalf & Eddy, Inc., SOLFIX
T0518 Met-Chem, Metal Kleen A
T0519 Met-Chem, Metal Kleen B (MCB)
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0529 Millgard Corporation, MecTool Remediation System
T0531 Mirage Systems, Inc., ChemChar Process
T0533 Molasses Treatment for Bioremediation—General
T0535 Molten Metal Technology, Inc., Quantum Catalytic Extraction Process (Q-CEP)
T0536 Molten Salt Oxidation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0562 North American Technologies Group, Inc., System IV
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0582 Onyx Industrial Services, SOIL*EX
T0583 Oregon State University, Chitosan Beads
T0586 Pacific Northwest National Laboratory, In Situ Redox Manipulation
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0594 PEAT, Inc., Thermal Destruction and Recovery
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0608 Phytoremediation: Hyperaccumulation—General
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0613 Plasma Vitrification—General
T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System
T0615 Polymer-Based Solidification/Stabilization—General
T0616 Pozzolanic Solidification/Stabilization—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0624 Proactive Applied Solutions Corporation, LEADX

T0644 Recra Environmental, Inc., Alternating Current Electrocoagulation
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0657 Resonant Shock Compaction, L.L.C., Resonant Shock Compaction
T0658 Resource Management and Recovery, AlgaSORB
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0667 RMT, Inc., Metal Treatment Technology (MTTTM)
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0678 S.G. Frantz Company, Inc., Magnetic Barrier Separation
T0682 Sandia National Laboratories, Electrokinetic Remediation
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0692 SCC Environmental, Micro-Flo
T0696 Science Applications International Corporation, Plasma Hearth Process
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0726 Solidification/Stabilization—General
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0730 Solucorp Industries, Ltd., Molecular Bonding System
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0741 Stark Encapsulation, Inc., METLCAP Chemical Cement
T0742 Starmet Corporation, RocTec Stabilization
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0772 Terra Vac, Geochemical Fixation
T0773 Terra Vac, Heap Leaching
T0789 Texilla Environmental, Inc., Synthetic Mineral Immobilization Technology (SMITE)
T0801 Thermoplastic Stabilization/Solidification—General
T0808 Toledo Engineering Company, Inc., High-Temperature Joule-Heated Vitrification
T0818 TVIES, Inc., Soil Washing
T0819 U.S. Department of Energy Laboratories, Enhanced Sludge Washing
T0820 U.S. Environmental Protection Agency, Reductive Anaerobic Biological In Situ Treatment (RABIT)
T0821 U.S. EPA and IT Corporation, Debris Washing System
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0858 Versar, Inc., Chemical Reduction of Hexavalent Chromium Contaminated Soils
T0862 Vortec Corporation, Cyclone Melting System (CMS)
T0871 WASTECH, Inc., Solidification and Stabilization
T0874 Water Technology International Corporation, Self-Sealing/Self-Healing Barrier (SS/SH)
T0880 Western Product Recovery Group, Inc., Coordinate Chemical Bonding and Adsorption (CCBA) Process
T0882 Westinghouse Hanford Company, In Situ Gaseous Reduction System
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0899 Zenon Environmental Systems, Inc., ZenoGem

CHROMIUM-CONTAINING IONIC SPECIES

Chromate Ion, Hexavalent Chromium

T0004 Activated Alumina—General
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0050 Aquathermolysis—General
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0066 Argonne National Laboratory, Transuranium Extraction (TRUEX) Process
T0080 Battelle Memorial Institute, Electroacoustic Dewatering
T0081 Battelle Memorial Institute, Liquid–Liquid Extraction of Metals (LLX)
T0127 Blast Fracturing—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0155 CFX Corporation, CFX MiniFix
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0200 Delphi Research, Inc., DETOX
T0235 Electrochemical Treatment of Contaminated Groundwater—General
T0236 Electrokinetic Remediation—General
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0279 Environmental Research and Development, Inc., Neutral Process for Heavy Metals Removal
T0285 Environmental Technology (U.S.), Inc., TR-Detox
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0404 In Situ Grouting—General
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0529 Millgard Corporation, MecTool Remediation System
T0533 Molasses Treatment for Bioremediation—General
T0544 National Renewable Energy Laboratory Solar Detoxification of Water
T0546 Natural Attenuation—General
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0586 Pacific Northwest National Laboratory, In Situ Redox Manipulation
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0599 PerkinElmer, Inc., NoVOCs
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0607 Phytoremediation—General
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0682 Sandia National Laboratories, Electrokinetic Remediation
T0696 Science Applications International Corporation, Plasma Hearth Process
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0730 Solucorp Industries, Ltd., Molecular Bonding System
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0772 Terra Vac, Geochemical Fixation
T0820 U.S. Environmental Protection Agency, Reductive Anaerobic Biological In Situ Treatment (RABIT)
T0837 Unipure Environmental, Unipure Process Technology
T0858 Versar, Inc., Chemical Reduction of Hexavalent Chromium Contaminated Soils

T0882 Westinghouse Hanford Company, In Situ Gaseous Reduction System
T0888 Wet Oxidation—General
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process

COBALT

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0023 Affinity Water Technologies, Advanced Affinity Chromatography
T0054 Arctech, Inc., Humasorb
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0118 Biosorption—General
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0218 Dynaphore, Inc., Forager Sponge Technology
T0232 Eichrom Industries, Inc., Diphonix
T0236 Electrokinetic Remediation—General
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0279 Environmental Research and Development, Inc, Neutral Process for Heavy Metals Removal
T0280 Environmental Research and Development, Inc., Ice Electrode
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0344 Geosafe Corporation, In Situ Vitrification
T0377 Horsehead Resource Development Company, Inc., Flame Reactor
T0452 Joule-Heated Vitrification—General
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0510 Metals Recovery, Inc., Metals Leaching
T0519 Met-Chem, Metal Kleen B (MCB)
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0535 Molten Metal Technology, Inc., Quantum Catalytic Extraction Process (Q-CEP)
T0536 Molten Salt Oxidation—General
T0546 Natural Attenuation—General
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0692 SCC Environmental, Micro-Flo
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0798 Thermo NUClean, Segmented Gate System (SGS)
T0819 U.S. Department of Energy Laboratories, Enhanced Sludge Washing
T0850 UOP, Inc., Ionsiv IE-911 Ion Exchange Resins

T0874 Water Technology International Corporation, Self-Sealing/Self-Healing Barrier (SS/SH)

COPPER

T0001 3M Company, 3M Empore Extraction Disk
T0015 Advanced Recovery Systems, Inc., DeHg
T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0023 Affinity Water Technologies, Advanced Affinity Chromatography
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0054 Arctech, Inc., Humasorb
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0080 Battelle Memorial Institute, Electroacoustic Dewatering
T0081 Battelle Memorial Institute, Liquid–Liquid Extraction of Metals (LLX)
T0090 Beco Engineering Company, Alka/Sorb
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0107 Biomet Mining Solutions Corporation, Biosulfide Process
T0118 Biosorption—General
T0124 BioTrol, Inc., Soil Washing Technology
T0131 Brice Environmental Services Corporation (BESCORP), Soil Washing System (BSWS)
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0149 Cement-Based Stabilization/Solidification—General
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0158 CH2M Hill, Phytoremediation-Based Systems
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0162 Chemical Precipitation of Metals—General
T0176 Concurrent Technologies Corporation, Acid Extraction Treatment System (AETS)
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0207 Doe Run Company, TERRAMET Heavy-Metal Removal Technology
T0214 DuPont/Oberlin, Microfiltration Technology
T0218 Dynaphore, Inc., Forager Sponge Technology
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0232 Eichrom Industries, Inc., Diphonix
T0235 Electrochemical Treatment of Contaminated Groundwater—General
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0279 Environmental Research and Development, Inc., Neutral Process for Heavy-Metals Removal
T0280 Environmental Research and Development, Inc., Ice Electrode
T0285 Environmental Technology (U.S.), Inc., TR-Detox
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0301 Evaporation for Wastewater Treatment—General
T0306 Ferro Corporation, Waste Vitrification through Electric Melting
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method

T0313 Forrester Environmental Services, Inc., Heavy-Metal Stabilization
T0320 Funderburk & Associates, Solidification Process
T0322 G.E.M., Inc., Treatment of Chromated Copper Arsenate (CCA) in Wood Products
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0344 Geosafe Corporation, In Situ Vitrification
T0352 Golder Associates Corporation, Montan Wax Barrier
T0377 Horsehead Resource Development Company, Inc., Flame Reactor
T0378 HPT Research, Inc., Ionic State Modification (ISM) Process for the Treatment of Acid Mine Drainage
T0382 Humboldt State University, Chitosan Derivative
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0418 Integrated Chemistries, Inc., Metraxt
T0426 International Environmental Trading Company, Inc., Metals Extraction and Recycling System
T0428 International Landmark Environmental, Inc., Diatomite
T0443 IT Corporation, In Situ Geochemical Fixation
T0452 Joule-Heated Vitrification—General
T0461 Kinit Enterprises, Trozone Soil Remediation System
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0469 Kvaerner Metals, Resin-in-Pulp/Carbon-in-Pulp
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0477 Lehigh University, Hybrid Inorganic Solvent HISORB
T0478 Lewis Environmental Services, Inc., Soil-Leaching and Enviro-Clean Technologies
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0488 Lynntech, Inc., Electrokinetic Remediation of Contaminated Soil
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0496 MARCOR Remediation, Inc., Advanced Chemical Treatment
T0510 Metals Recovery, Inc., Metals Leaching
T0511 Metals Removal Via Peat—General
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0518 Met-Chem, Metal Kleen A
T0519 Met-Chem, Metal Kleen B (MCB)
T0521 Met-Tech, Inc., Metal Separation by Liquid Ion Exchange
T0525 Microbial & Aquatic Treatment Systems, Inc., (MATS) Biomats
T0529 Millgard Corporation, MecTool Remediation System
T0536 Molten Salt Oxidation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0546 Natural Attenuation—General
T0562 North American Technologies Group, Inc., System IV
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0583 Oregon State University, Chitosan Beads
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0608 Phytoremediation: Hyperaccumulation—General
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System
T0615 Polymer-Based Solidification/Stabilization—General
T0616 Pozzolanic Solidification/Stabilization—General

T0624 Proactive Applied Solutions Corporation, LEADX
T0644 Recra Environmental, Inc., Alternating Current Electrocoagulation
T0658 Resource Management and Recovery, AlgaSORB
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0667 RMT, Inc., Metal Treatment Technology (MTTTM)
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0692 SCC Environmental, Micro-Flo
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0719 Soil/Sediment Washing—General
T0726 Solidification/Stabilization—General
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0730 Solucorp Industries, Ltd., Molecular Bonding System
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0763 Tallon, Inc., Virtokele
T0765 Technology Scientific, Ltd., Flow Consecutor Technology (FCT)
T0772 Terra Vac, Geochemical Fixation
T0773 Terra Vac, Heap Leaching
T0801 Thermoplastic Stabilization/Solidification—General
T0817 T-Thermal Company, Submerged Quench Incineration
T0818 TVIES, Inc., Soil Washing
T0821 U.S. EPA and IT Corporation, Debris Washing System
T0824 U.S. Filter Corporation, WESPHix
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0849 University of Washington, Metals Treatment by Adsorptive Filtration
T0857 Vendor Unknown, Calochroma Soil Washing
T0860 Viatec Recovery Systems, Inc., Waste Acid Detoxification and Reclamation
T0862 Vortec Corporation, Cyclone Melting System (CMS)
T0874 Water Technology International Corporation, Self-Sealing/Self-Healing Barrier (SS/SH)
T0880 Western Product Recovery Group, Inc., Coordinate Chemical Bonding and Adsorption (CCBA) Process
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0899 Zenon Environmental Systems, Inc., ZenoGem

CYCLIC ETHERS

Cyclic Ethers

T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0127 Blast Fracturing—General
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0355 Granular Activated Carbon (GAC)—General

T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0596 Pecan-Based Granular Activated Carbon—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Dioxane-1,4

T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0127 Blast Fracturing—General
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0596 Pecan-Based Granular Activated Carbon—General
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Ethylene Oxide

T0355 Granular Activated Carbon (GAC)—General
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

DIHALOGENATED AND POLYHALOGENATED ETHERS

Dichloroethyl, 1,1-Ether

T0320 Funderburk & Associates, Solidification Process
T0355 Granular Activated Carbon (GAC)—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)

Dichloromethyl, 1,1-Ether; Methyl-dichloro-1,1-ether

T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

Dieldrin

T0001 3M Company, 3M Empore Extraction Disk
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0114 Bioremediation Technology Services, Inc., BTS Method
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)

T0124 BioTrol, Inc., Soil Washing Technology
T0138 Calgon Carbon Corporation, Perox-Pure
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0323 G.E.M., Inc., Chemical Treatment
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0400 IIT Research Institute, Radio Frequency Heating
T0452 Joule-Heated Vitrification—General
T0499 Maxymillian Technologies, Inc., Indirect System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0755 Supercritical Carbon Dioxide Extraction—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0794 Thermal Desorption—General
T0817 T-Thermal Company, Submerged Quench Incineration
T0889 White-Rot Fungus—General

Dihalogenated and Polyhalogenated Ethers

T0001 3M Company, 3M Empore Extraction Disk
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0114 Bioremediation Technology Services, Inc., BTS Method
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0124 BioTrol, Inc., Soil Washing Technology
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0138 Calgon Carbon Corporation, Perox-Pure
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0320 Funderburk & Associates, Solidification Process
T0323 G.E.M., Inc., Chemical Treatment
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0400 IIT Research Institute, Radio Frequency Heating
T0416 Intech One Eighty, White-Rot Fungus
T0452 Joule-Heated Vitrification—General

T0499 Maxymillian Technologies, Inc., Indirect System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0755 Supercritical Carbon Dioxide Extraction—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0817 T-Thermal Company, Submerged Quench Incineration
T0889 White-Rot Fungus—General

Endrin

T0001 3M Company, 3M Empore Extraction Disk
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0320 Funderburk & Associates, Solidification Process
T0323 G.E.M., Inc., Chemical Treatment
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0400 IIT Research Institute, Radio Frequency Heating
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0755 Supercritical Carbon Dioxide Extraction—General
T0794 Thermal Desorption—General
T0817 T-Thermal Company, Submerged Quench Incineration

Trichlorophenoxyacetic, 2,4,5 Acid

T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0416 Intech One Eighty, White-Rot Fungus
T0889 White-Rot Fungus—General

DIOXIN AND RELATED COMPOUNDS

Dioxin and Related Compounds

T0001 3M Company, 3M Empore Extraction Disk
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0053 ARCADIS Geraghty and Miller, Inc., STRATEX (Stratified Temperature Extractor)
T0090 Beco Engineering Company, Alka/Sorb

T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0138 Calgon Carbon Corporation, Perox-Pure
T0143 Carson Environmental, Low-Temperature Oxidation
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0161 Chemical Oxidation—General
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0204 Distillation—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0266 Envirogen, Inc., Solid Organic Phase Extraction (SoPE)
T0276 Environmental Recycling, L.L.C., Asphalt-Stabilized Base/Engineered Backfill
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0299 ETG Environmental, Inc., Thermo-O-Detox Medium Temperature Thermal Desorption (MTTD)
T0325 Galson Remediation Corporation, APEG-PLUS Process
T0329 General Atomics, MODAR Supercritical Water Oxidation
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0355 Granular Activated Carbon (GAC)—General
T0411 Institute of Gas Technology, Fluid Extraction—Biological Degradation
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0446 IT Corporation, Photolytic and Biological Soil Detoxification
T0449 IT Corporation, Thermal Desorption
T0452 Joule-Heated Vitrification—General
T0459 King, Buck Technologies, Inc., HD CatOx System
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0516 Metcalf & Eddy, Inc., ORG-X
T0559 NORIT, N.V., Porta-PAC
T0604 Philip Environmental Services Corporation, Thermal Recycling System
T0613 Plasma Vitrification—General
T0619 Praxair, Inc., Oxygen Combustion System
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0689 SBP Technologies, Inc., Membrane Filtration
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0699 SDTX Technologies, Inc., KPEG
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0711 Shirco Infrared Systems, Inc., Shirco Infrared Thermal Destruction System
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0719 Soil/Sediment Washing—General
T0723 Soil Technology, Inc., Remediation Technologies Using Electrolytically Produced Water
T0733 Sonotech, Inc., Cello Pulse Combustion BurnerSystem
T0746 STC Remediation, Inc., Solidification/Stabilization Technology

T0756 Supercritical Water Oxidation—General
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0821 U.S. EPA and IT Corporation, Debris Washing System
T0822 U.S. EPA National Risk Management Research Laboratory, Base-Catalyzed Decomposition
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0853 UV Technologies, Inc., UV-CATOX Technology
T0867 Waste Management, Inc., DeChlor/KGME Process
T0889 White-Rot Fungus—General
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat
T0901 Zeros USA, Inc., Zero-Emission Energy Recycling System (ZEROS)

HxCDF; Hexachlorodibenzofurans

T0090 Beco Engineering Company Alka/Sorb
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0459 King, Buck Technologies, Inc., HD CatOx System
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0692 SCC Environmental, Micro-Flo
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0867 Waste Management, Inc., DeChlor/KGME Process

TCDD; Tetrachlorodibenzodioxins

T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0325 Galson Remediation Corporation, APEG-PLUS Process
T0329 General Atomics, MODAR Supercritical Water Oxidation
T0344 Geosafe Corporation, In Situ Vitrification
T0355 Granular Activated Carbon (GAC)—General
T0446 IT Corporation, Photolytic and Biological Soil Detoxification
T0459 King, Buck Technologies, Inc., HD CatOx System
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0699 SDTX Technologies, Inc., KPEG
T0711 Shirco Infrared Systems, Inc., Shirco Infrared Thermal Destruction System
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0719 Soil/Sediment Washing—General
T0723 Soil Technology, Inc., Remediation Technologies Using Electrolytically Produced Water

T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0822 U.S. EPA National Risk Management Research Laboratory, Base-Catalyzed Decomposition
T0867 Waste Management, Inc., DeChlor/KGME Process
T0889 White-Rot Fungus—General

TCDF; Tetrachlorodibenzofurans

T0090 Beco Engineering Company, Alka/Sorb
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0325 Galson Remediation Corporation, APEG-PLUS Process
T0329 General Atomics, Supercritical Water Oxidation
T0344 Geosafe Corporation, In Situ Vitrification
T0355 Granular Activated Carbon (GAC)—General
T0459 King, Buck Technologies, Inc., HD CatOx System
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0794 Thermal Desorption—General
T0822 U.S. EPA National Risk Management Research Laboratory, Base-Catalyzed Decomposition
T0867 Waste Management, Inc., DeChlor/KGME Process

DISUBSTITUTED AND POLYSUBSTITUTED BENZENE HYDROCARBONS

Diethyl Benzene

T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads

Disubstituted and Polysubstituted Benzene Hydrocarbons

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 Allied Signal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter

T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0049 Aqualogy BioRemedics, OptiSorb Encapsulate
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0067 Ariel Industries, Inc., Ariel SST Low-Temperature Thermal Desorber
T0068 Armstrong Laboratory Environics Directorate, Phase-Transfer Oxidation
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0093 Bio Solutions, Inc., Soil Slurry-Sequencing Batch Reactor
T0096 BioEnviroTech, Inc., BioPetro
T0098 BioGee International, Inc., BioGee HC
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0104 Biogenie, Inc., Biogenie Biofiltration Process
T0105 Biogenie, Inc., Biogenie Biopile
T0106 Biological Activated Carbon—General
T0108 Biomin, Inc., Organoclay
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0113 Bioremediation Service, Inc., AquaPlant Biofilter System
T0114 Bioremediation Technology Services, Inc., BTS Method
T0115 Bioscience, Inc., BIOX Biotreater
T0117 Bioslurping—General
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0122 Biotrickling Filter—General
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0143 Carson Environmental, Low-Temperature Oxidation
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0158 CH2M Hill, Phytoremediation-Based Systems
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0164 ChemPete, Inc., Bioremediation
T0168 CleanSoil, Inc., CleanSoil Process
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0177 Conor Pacific, WINDsparge
T0178 Constructed Wetlands—General
T0182 ConTeck Environmental Services, Inc., Soil Roaster

T0185 Corrpro Companies Incorporated, Electroremediation
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0197 Dames and Moore, Two-Phase Vacuum Extraction
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0200 Delphi Research, Inc., DETOX
T0201 Delta Cooling Towers, Inc., Aqua-Trim and Vanguard Air Strippers
T0202 Detox Industries, Inc., DETOX Process
T0208 Donald L. Geisel & Associates, Inc., HeatTrode Thermally Accelerated In Situ Bioremediation
T0212 Dual-Phase Extraction—General
T0215 DuraTherm, Inc., DuraTherm Desorption
T0222 Earth Purification Engineering, Inc., Soil Cleanup System (SCS)
T0223 Earth Tech, Bioremediation—Solid Phase
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0228 ECO-TEC, Inc., EnviroMech Gold Biocatalytic Contaminant Degradation
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized Bed Reactor (GAC FBR) Process
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0256 Ensite, Inc., SafeSoil
T0257 EnSolve Biosystems, Inc., EnCell Bioreactor
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0278 Environmental Remediation International (EnRem), Ltd., Soil Remediation System (SRS)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0290 Enviro-Soil Remediation, Inc., Thermal Stripping
T0292 EnviroWall, Inc., EnviroWall Barrier
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0295 EOD Technology, Inc., Biotechnical Processing of Explosives
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0309 Fixed-Bed Soil Biofilters—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0329 General Atomics, Supercritical Water Oxidation
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0344 Geosafe Corporation, In Situ Vitrification
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0348 GHEA Associates, Soil Washing Technology
T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0352 Golder Associates Corporation, Montan Wax Barrier
T0355 Granular Activated Carbon (GAC)—General
T0356 Groundwater Recovery Systems, Inc., OXY 1
T0360 H&H Eco Systems, Inc., Microenfractionator
T0363 Harding ESE, Inc., PetroClean Bioremediation System

T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0369 Heaven from Earth, Inc., Organic Cleaners
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process, In Situ
T0380 Hrubetz Environmental Services, Inc., HRUBOUT Process, Ex Situ
T0384 Hydraulic Fracturing—General
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0388 Hydrogen Peroxide In Situ Bioremediation—General
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0405 In Situ Oil Skimmers—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0412 Institute of Gas Technology, MGP-REM
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0434 IT Corporation, Biological Polishing Treatment
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0449 IT Corporation, Thermal Desorption
T0452 Joule-Heated Vitrification—General
T0454 KAL CON Environmental Services, Thermal Desorption
T0457 KEMRON Environmental Services, Inc., Bioremediation—Soil and Groundwater
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0476 Lehigh University, Ground Rubber as a Reactive Permeable Barrier Sorption Media
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0489 M.L. Chartier, Inc., Therminator
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0495 Maple Engineering Services, Inc., Biopur
T0496 MARCOR Remediation, Inc., Advanced Chemical Treatment
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0500 Maxymillian Technologies, Inc., Thermal Desorption System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0504 Medina Agricultural Products Company, Inc., Medina Bioremediation Products
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General

T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0530 MIOX Corporation, Miox System
T0532 Modified Natural Clays—General
T0541 MYCELX Technologies Corporation, MYCELX
T0546 Natural Attenuation—General
T0547 NEPCCO Environmental Systems, SoilPurge
T0552 NEPCCO Environmental Systems, Photocatalytic Oxidation Technology
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0561 North American Drilling Technologies (NADT), Inc., EnviroZyme
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0566 NUCON International, Inc., Brayton Cycle
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation
T0573 O'Brien & Gere Engineers, Inc., Mechanical Volatilization Screening
T0577 On-Site Technologies, Modular Interchangeable Treatment System (MITS)
T0578 OnSite Technology, L.L.C., Portable Indirect Thermal Desorption (ITD)
T0584 Osprey Biotechnics, Munox
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0592 Passive Soil Vapor Extraction—General
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0602 Pet-Con Soil Remediation, Inc., Thermal Desorption
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0613 Plasma Vitrification—General
T0617 PPC Biofilter, Biofiltration Systems
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0626 Product Services Company, Oil Gator
T0628 PTC Enterprises, BioTreat System
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0638 R.E. Wright Environmental, Inc., Steam-Enhanced Recovery
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0656 Remtech Engineers, Bubble Lance Low-Profile Diffused Air Stripper
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0661 Reverse Osmosis—General
T0668 Rochem Environmental, Inc., Disc Tube

T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0676 Rusmar, Inc., Long-Duration Foam
T0680 S.S. Papadopulos & Associates, Inc., DeNAPLs (Detergent Extraction of NAPLs)
T0689 SBP Technologies, Inc., Membrane Filtration
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0732 Solvent Extraction—General
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0735 Sound Remedial Technologies, Inc., Hot Air Vapor Extraction (HAVE)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0750 Stevens Institute of Technology, Trench Bio-Sparge
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0756 Supercritical Water Oxidation—General
T0759 Surfactants—General
T0761 Sybron Chemicals, Inc., ABR (Augmented Bioreclamation) Microbial Blends
T0764 Tarmac Environmental Company, Inc., Thermal Desorption
T0768 Tekno Associates, Biolift
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0792 The Westford Chemical Corporation, BioSolv
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0802 ThermoRetec, Microbial Fence
T0805 ThermoRetec, Thermatek Thermal Desorption
T0811 TPS Technologies, Inc., Thermal Desorption
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0838 United Retek Corporation, Asphalt Emulsion Stabilization

T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0847 University of New South Wales, Upflow Washing
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0870 Waste Stream Technology, Inc., Bioremediation
T0871 WASTECH, Inc., Solidification and Stabilization
T0873 Water Equipment Services, Inc., Environmental Division Vacu-Point
T0890 WIK Associates, Inc., Bugs+Plus
T0891 Williams Environmental, RamSorb-1
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0897 Yellowstone Environmental Science, Inc., (YES), Biocat
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0899 Zenon Environmental Systems, Inc., ZenoGem
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Ethyltoluene

T0161 Chemical Oxidation—General
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)

Indene; Dihydroindene

T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0794 Thermal Desorption—General

Trimethyl Benzene

T0126 Bioventing—General
T0161 Chemical Oxidation—General
T0200 Delphi Research, Inc., DETOX
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0546 Natural Attenuation—General
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0607 Phytoremediation—General
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0676 Rusmar, Inc., Long-Duration Foam
T0833 Ultraviolet Oxidation (UV/Oxidation)—General

Xylenes

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone

T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 Allied Signal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0049 Aqualogy BioRemedics, OptiSorb Encapsulate
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0067 Ariel Industries, Inc., Ariel SST Low-Temperature Thermal Desorber
T0068 Armstrong Laboratory Environics Directorate, Phase-Transfer Oxidation
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0093 Bio Solutions, Inc., Soil Slurry-Sequencing Batch Reactor
T0096 BioEnviroTech, Inc., BioPetro
T0098 BioGee International, Inc., BioGee HC
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0104 Biogenie, Inc., Biogenie Biofiltration Process
T0105 Biogenie, Inc., Biogenie Biopile
T0106 Biological Activated Carbon—General
T0108 Biomin, Inc., Organoclay
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0113 Bioremediation Service, Inc., AquaPlant Biofilter System
T0114 Bioremediation Technology Services, Inc., BTS Method
T0115 Bioscience, Inc., BIOX Biotreater
T0117 Bioslurping—General
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0122 Biotrickling Filter—General
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0143 Carson Environmental, Low-Temperature Oxidation
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0158 CH2M Hill, Phytoremediation-Based Systems
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0164 ChemPete, Inc., Bioremediation
T0168 CleanSoil, Inc., CleanSoil Process

T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0177 Conor Pacific, WINDsparge
T0178 Constructed Wetlands—General
T0182 ConTeck Environmental Services, Inc., Soil Roaster
T0185 Corrpro Companies, Inc., Electroremediation
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0197 Dames and Moore, Two-Phase Vacuum Extraction
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0200 Delphi Research, Inc., DETOX
T0201 Delta Cooling Towers, Inc., Aqua-Trim and Vanguard Air Strippers
T0202 Detox Industries, Inc., DETOX Process
T0208 Donald L. Geisel & Associates, Inc., HeatTrode Thermally Accelerated In Situ Bioremediation
T0212 Dual-Phase Extraction—General
T0215 DuraTherm, Inc., DuraTherm Desorption
T0222 Earth Purification Engineering, Inc., Soil Cleanup System (SCS)
T0223 Earth Tech, Bioremediation—Solid Phase
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0228 ECO-TEC, Inc., EnviroMech Gold Biocatalytic Contaminant Degradation
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized Bed Reactor (GAC FBR) Process
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0256 Ensite, Inc., SafeSoil
T0257 EnSolve Biosystems, Inc., EnCell Bioreactor
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0278 Environmental Remediation International (EnRem), Ltd., Soil Remediation System (SRS)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0290 Enviro-Soil Remediation, Inc., Thermal Stripping
T0292 EnviroWall, Inc., EnviroWall Barrier
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0295 EOD Technology, Inc., Biotechnical Processing of Explosives
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0309 Fixed-Bed Soil Biofilters—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0329 General Atomics, Supercritical Water Oxidation
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0344 Geosafe Corporation, In Situ Vitrification
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0348 GHEA Associates, Soil Washing Technology

T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0352 Golder Associates Corporation, Montan Wax Barrier
T0355 Granular Activated Carbon (GAC)—General
T0356 Groundwater Recovery Systems, Inc., OXY 1
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0369 Heaven from Earth, Inc., Organic Cleaners
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process, In Situ
T0380 Hrubetz Environmental Services, Inc., HRUBOUT Process, Ex Situ
T0384 Hydraulic Fracturing—General
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0388 Hydrogen Peroxide In Situ Bioremediation—General
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0405 In Situ Oil Skimmers—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0412 Institute of Gas Technology, MGP-REM
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0434 IT Corporation, Biological Polishing Treatment
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0449 IT Corporation, Thermal Desorption
T0452 Joule-Heated Vitrification—General
T0454 KAL CON Environmental Services, Thermal Desorption
T0457 KEMRON Environmental Services, Inc., Bioremediation—Soil and Groundwater
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0476 Lehigh University, Ground Rubber as a Reactive Permeable Barrier Sorption Media
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0489 M.L. Chartier, Inc., Therminator
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0495 Maple Engineering Services, Inc., Biopur
T0496 MARCOR Remediation, Inc., Advanced Chemical Treatment
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0500 Maymillian Technologies, Inc., Thermal Desorption System

T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0504 Medina Agricultural Products Company, Inc., Medina Bioremediation Products
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0530 MIOX Corporation, Miox System
T0532 Modified Natural Clays—General
T0541 MYCELX Technologies Corporation, MYCELX
T0546 Natural Attenuation—General
T0547 NEPCCO, Environmental Systems SoilPurge
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0561 North American Drilling Technologies (NADT), Inc., EnviroZyme
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0566 NUCON International, Inc., Brayton Cycle
T0571 Oak Ridge National Laboratory (ISCOR), In Situ Chemical Oxidation through Recirculation
T0573 O'Brien & Gere Engineers, Inc., Mechanical Volatilization Screening
T0577 On-Site Technologies, Modular Interchangeable Treatment System (MITS)
T0578 OnSite Technology, L.L.C., Portable Indirect Thermal Desorption (ITD)
T0584 Osprey Biotechnics, Munox
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0592 Passive Soil Vapor Extraction—General
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0602 Pet-Con Soil Remediation, Inc., Thermal Desorption
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0613 Plasma Vitrification—General
T0617 PPC Biofilter, Biofiltration Systems
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0626 Product Services Company, Oil Gator
T0628 PTC Enterprises, BioTreat System
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0638 R.E. Wright Environmental, Inc., Steam-Enhanced Recovery
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System

T0656 Remtech Engineers, Bubble Lance Low-Profile Diffused Air Stripper
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0661 Reverse Osmosis—General
T0668 Rochem Environmental, Inc., Disc Tube
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0676 Rusmar, Inc., Long-Duration Foam
T0680 S.S. Papadopulos & Associates, Inc., DeNAPLs (Detergent Extraction of NAPLs)
T0689 SBP Technologies, Inc., Membrane Filtration
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0732 Solvent Extraction—General
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0735 Sound Remedial Technologies, Inc., Hot Air Vapor Extraction (HAVE)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0750 Stevens Institute of Technology, Trench Bio-Sparge
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0756 Supercritical Water Oxidation—General
T0759 Surfactants—General
T0761 Sybron Chemicals, Inc., ABR (Augmented Bioreclamation) Microbial Blends
T0764 Tarmac Environmental Company, Inc., Thermal Desorption
T0768 Tekno Associates, Biolift
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0792 The Westford Chemical Corporation BioSolv
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0802 ThermoRetec, Microbial Fence
T0805 ThermoRetec, Thermatek Thermal Desorption
T0811 TPS Technologies, Inc., Thermal Desorption
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)

T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0847 University of New South Wales, Upflow Washing
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0870 Waste Stream Technology, Inc., Bioremediation
T0871 WASTECH, Inc., Solidification and Stabilization
T0873 Water Equipment Services, Inc., Environmental Division Vacu-Point
T0890 WIK Associates, Inc., Bugs+Plus
T0891 Williams Environmental, RamSorb-1
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0899 Zenon Environmental Systems, Inc., ZenoGem
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

ELEMENTAL SULFUR

T0151 Ceramic Immobilization of Radioactive Wastes—General
T0756 Supercritical Water Oxidation—General
T0789 Texilla Environmental, Inc., Synthetic Mineral Immobilization Technology (SMITE)

ESTERS

Butyl Acrylate; Propenoic Acid, Butyl Ester

T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads

Esters

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0093 Bio Solutions, Inc., Soil Slurry-Sequencing Batch Reactor
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction

T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0178 Constructed Wetlands—General
T0195 DAHL & Associates, Inc., ThermNet
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0256 Ensite, Inc., SafeSoil
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0309 Fixed-Bed Soil Biofilters—General
T0320 Funderburk & Associates, Solidification Process
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0373 Horizontal Drilling—General
T0400 IIT Research Institute, Radio Frequency Heating
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0453 Kaiser-Hill Company, L.L.C., Supercritical Carbon Dioxide Extraction
T0459 King, Buck Technologies, Inc., HD CatOx System
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0541 MYCELX Technologies Corporation, MYCELX
T0617 PPC Biofilter, Biofiltration Systems
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0672 Rohm and Haas Company, Ambersorb 600
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0794 Thermal Desorption—General
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0855 Vapor-Phase Biofiltration—General
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0869 Waste Microbes International (WMI), Inc., WMI-2000
T0899 Zenon Environmental Systems, Inc., ZenoGem

Ethyl Acetate

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0617 PPC Biofilter, Biofiltration Systems
T0756 Supercritical Water Oxidation—General
T0855 Vapor-Phase Biofiltration—General

Ethyl Acrylate

T0355 Granular Activated Carbon (GAC)—General
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent

Ethyl Lactate; Hydroxypropanoic Acid, Ethyl Ester

T0672 Rohm and Haas Company, Ambersorb 600

Methyl Methacrylate

T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0899 Zenon Environmental Systems, Inc., ZenoGem

Phthalate, Butyl Benzyl; Butyl Benzyl Phthalate

T0001 3M Company, 3M Empore Extraction Disk
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0138 Calgon Carbon Corporation, Perox-Pure
T0373 Horizontal Drilling—General
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0794 Thermal Desorption—General
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0838 United Retek Corporation, Asphalt Emulsion Stabilization

Phthalate, Dibutyl; Dibutyl Phthalate, *n*

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0320 Funderburk & Associates, Solidification Process
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0868 Waste Management, Inc., X*TRAX Thermal Desorption

Phthalate, Diethylhexyl; Diethylhexyl Phthalate

T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0093 Bio Solutions, Inc., Soil Slurry-Sequencing Batch Reactor
T0138 Calgon Carbon Corporation, Perox-Pure
T0195 DAHL & Associates, Inc., ThermNet

T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0256 Ensite, Inc., SafeSoil
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0320 Funderburk & Associates, Solidification Process
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0400 IIT Research Institute, Radio Frequency Heating
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0794 Thermal Desorption—General
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0868 Waste Management, Inc., X*TRAX Thermal Desorption

Phthalate, Dimethyl; Dimethyl Phthalate

T0001 3M Company, 3M Empore Extraction Disk
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0178 Constructed Wetlands—General
T0320 Funderburk & Associates, Solidification Process
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0775 Terra Vac, Inc., Dual-Vacuum Extraction

Phthalate, Dioctyl; Di-*n*-octyl Phthalate

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0320 Funderburk & Associates, Solidification Process
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0453 Kaiser-Hill Company, L.L.C., Supercritical Carbon Dioxide Extraction
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0755 Supercritical Carbon Dioxide Extraction—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)

Vinyl Acetate

T0168 CleanSoil, Inc., CleanSoil Process
T0470 Lambda Bioremediation Systems, Inc., Bioremediation

ETHERS

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0108 Biomin, Inc., Organoclay

T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0309 Fixed-Bed Soil Biofilters—General
T0355 Granular Activated Carbon (GAC)—General
T0422 InterBio, Petrobac
T0467 KSE, Inc., AIR-II Process
T0487 Louisiana State University, Colloidal Gas Aphron
T0541 MYCELX Technologies Corporation, MYCELX
T0617 PPC Biofilter, Biofiltration Systems
T0637 R.C. Costello and Associates, Inc., Actopentin Biomass Filter
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0834 Ultrox International/U.S. Filter, Ultrox Advanced Oxidation Process
T0853 UV Technologies, Inc., UV-CATOX Technology

FLUORIDE ION

T0014 Advanced Recovery Systems, Inc., DeCaF
T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0359 GTS Duratek, DuraMelter
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0466 Krudico, Inc., Ion Exchange Resins for Nitrate and Perchlorate
T0510 Metals Recovery, Inc., Metals Leaching
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0644 Recra Environmental, Inc., Alternating Current Electrocoagulation
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0860 Viatec Recovery Systems, Inc., Waste Acid Detoxification and Reclamation
T0862 Vortec Corporation, Cyclone Melting System (CMS)

GLYCOLS

Ethylene Glycol

T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0129 Bogart Environmental Services, Inc., MiKIE
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0161 Chemical Oxidation—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0329 General Atomics, Supercritical Water Oxidation
T0344 Geosafe Corporation, In Situ Vitrification
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0372 Hi-Point Industries, Ltd., Oclansorb

T0427 International Landmark Environmental, Inc., Aminoplast Capillary Technology
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0536 Molten Salt Oxidation—General
T0756 Supercritical Water Oxidation—General
T0776 Terra Vac, Inc., Oxy Vac
T0829 U.S. Microbics, Inc., Bio-Raptor
T0869 Waste Microbes International (WMI), Inc., WMI-2000
T0877 Weatherly, Inc., AQUA CRITOX

Glycols

T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0129 Bogart Environmental Services, Inc., MiKIE
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0161 Chemical Oxidation—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0329 General Atomics, Supercritical Water Oxidation
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0372 Hi-Point Industries, Ltd., Oclansorb
T0427 International Landmark Environmental, Inc., Aminoplast Capillary Technology
T0452 Joule-Heated Vitrification—General
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0536 Molten Salt Oxidation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0613 Plasma Vitrification—General
T0756 Supercritical Water Oxidation—General
T0776 Terra Vac, Inc., Oxy Vac
T0829 U.S. Microbics, Inc., Bio-Raptor
T0835 Umpqua Research Company, Low-Temperature Aqueous-Phase Catalytic Oxidation
T0869 Waste Microbes International (WMI), Inc., WMI-2000
T0877 Weatherly, Inc., AQUA CRITOX

Propylene Glycol

T0835 Umpqua Research Company, Low-Temperature Aqueous-Phase Catalytic Oxidation

Propylene Glycol Monoethyl Ether Acetate (PGMEA)

T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma

GLYCOLS, EPOXIDES

T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0541 MYCELX Technologies Corporation, MYCELX

GOLD

T0054 Arctech, Inc., Humasorb
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0279 Environmental Research and Development, Inc., Neutral Process for Heavy-Metals Removal
T0355 Granular Activated Carbon (GAC)—General
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0544 National Renewable Energy Laboratory Solar Detoxification of Water
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0594 PEAT, Inc., Thermal Destruction and Recovery
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0658 Resource Management and Recovery, AlgaSORB
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat

HALOGENATED AROMATIC COMPOUNDS

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0105 Biogenie, Inc., Biogenie Biopile
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0236 Electrokinetic Remediation—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0467 KSE, Inc., AIR-II Process
T0509 Metal-Based Permeable Reactive Barriers—General
T0541 MYCELX Technologies Corporation, MYCELX
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0692 SCC Environmental, Micro-Flo

T0693 SCC Environmental, Thermal-Phase Separation Unit
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General

HALOGENATED ETHERS AND EPOXIDES

T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)

HALOGENATED PHENOLIC COMPOUNDS

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0108 Biomin, Inc., Organoclay
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0236 Electrokinetic Remediation—General
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0308 First Environment, Inc., FE ACTIVE
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0449 IT Corporation, Thermal Desorption
T0509 Metal-Based Permeable Reactive Barriers—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0756 Supercritical Water Oxidation—General
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0834 Ultrox International/U.S. Filter, Advanced Oxidation Process
T0877 Weatherly, Inc., AQUA CRITOX

HALOPHENOLS

Chlorophenol

T0001 3M Company, 3M Empore Extraction Disk
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)

T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0323 G.E.M., Inc., Chemical Treatment
T0329 General Atomics, Supercritical Water Oxidation
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0501 MBI International, Anaerobic PCB Dechlorinating Granular Consortia
T0509 Metal-Based Permeable Reactive Barriers—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0661 Reverse Osmosis—General
T0692 SCC Environmental, Micro-Flo
T0756 Supercritical Water Oxidation—General
T0779 Terra Vac, Inc., Vacuum Extraction
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0853 UV Technologies, Inc., UV-CATOX Technology
T0877 Weatherly, Inc., AQUA CRITOX
T0889 White-Rot Fungus—General

Dichlorophenol

T0001 3M Company, 3M Empore Extraction Disk
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0236 Electrokinetic Remediation—General
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0509 Metal-Based Permeable Reactive Barriers—General
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0756 Supercritical Water Oxidation—General
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0877 Weatherly, Inc., AQUA CRITOX
T0889 White-Rot Fungus—General

Halophenols

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone

T0087 Battelle Pacific Northwest National Laboratory, Liquid Corona
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0108 Biomin, Inc., Organoclay
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0157 CH2M Hill, Waterflood Oil Recovery
T0158 CH2M Hill, Phytoremediation-Based Systems
T0161 Chemical Oxidation—General
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0167 Clean Technologies, Pyrodigestion
T0178 Constructed Wetlands—General
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0202 Detox Industries, Inc., DETOX Process
T0204 Distillation—General
T0236 Electrokinetic Remediation—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0299 ETG Environmental, Inc., Thermo-O-Detox Medium-Temperature Thermal Desorption (MTTD)
T0303 Extraksol (vendor unknown)
T0320 Funderburk & Associates, Solidification Process
T0323 G.E.M., Inc., Chemical Treatment
T0329 General Atomics, Supercritical Water Oxidation
T0335 Geo-Con, Inc., Deep Soil Mixing
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0376 Horner & Company, Max Bac
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0399 IEG Technologies, Groundwater Circulation Wells (GZB)
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0416 Intech One Eighty, White-Rot Fungus
T0419 Integrated Chemistries, Inc., Pentagone
T0437 IT Corporation, Engineered Bioremediation System
T0438 IT Corporation, Enhanced Natural Degradation (END)
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0444 IT Corporation, Oxygen Microbubble In Situ Bioremediation
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0448 IT Corporation, Slurry-Phase Bioremediation—Pilot Scale

T0452 Joule-Heated Vitrification—General
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0501 MBI International, Anaerobic PCB Dechlorinating Granular Consortia
T0506 Membran Corporation, Membrane Gas Transfer
T0509 Metal-Based Permeable Reactive Barriers—General
T0511 Metals Removal via Peat—General
T0532 Modified Natural Clays—General
T0542 Mycotech Corporation, Fungal Bioremediation
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0555 Niaski Environmental, Inc., Biopurge
T0556 Niaski Environmental, Inc., BioSparge System
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0628 PTC Enterprises, BioTreat System
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0661 Reverse Osmosis—General
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0719 Soil/Sediment Washing—General
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0756 Supercritical Water Oxidation—General
T0769 Terra Resources, Ltd., Terra Wash Soil Washing
T0779 Terra Vac, Inc., Vacuum Extraction
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0794 Thermal Desorption—General
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0818 TVIES, Inc., Soil Washing
T0822 U.S. EPA National Risk Management Research Laboratory, Base-Catalyzed Decomposition
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation

T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Advanced Oxidation Process
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0843 University of Cincinnati Department of Civil and Environmental Engineering, Reductive Electrolytic Dechlorination
T0852 U.S. EPA Risk Reduction Engineering Laboratory, Mobile Volume Reduction Unit (VRU)
T0853 UV Technologies, Inc., UV-CATOX Technology
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0877 Weatherly, Inc., AQUA CRITOX
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process

Pentachlorophenol; PCP

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0087 Battelle Pacific Northwest National Laboratory, Liquid Corona
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0108 Biomin, Inc., Organoclay
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0157 CH2M Hill, Waterflood Oil Recovery
T0158 CH2M Hill, Phytoremediation-Based Systems
T0161 Chemical Oxidation—General
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0167 Clean Technologies, Pyrodigestion
T0178 Constructed Wetlands—General
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0202 Detox Industries, Inc., DETOX Process
T0204 Distillation—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0299 ETG Environmental, Inc., Thermo-O-Detox Medium-Temperature Thermal Desorption (MTTD)
T0303 Extraksol (vendor unknown)
T0320 Funderburk & Associates, Solidification Process
T0335 Geo-Con, Inc., Deep Soil Mixing
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator

T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0376 Horner & Company, Max Bac
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0399 IEG Technologies, Groundwater Circulation Wells (GZB)
T0407 In Situ Steam-Enhanced Extraction—General
T0416 Intech One Eighty, White-Rot Fungus
T0419 Integrated Chemistries, Inc., Pentagone
T0437 IT Corporation, Engineered Bioremediation System
T0438 IT Corporation, Enhanced Natural Degradation (END)
T0442 IT Corporation, In Situ Air Sparging
T0444 IT Corporation, Oxygen Microbubble In Situ Bioremediation
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0448 IT Corporation, Slurry-Phase Bioremediation—Pilot Scale
T0452 Joule-Heated Vitrification—General
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0506 Membran Corporation, Membrane Gas Transfer
T0509 Metal-Based Permeable Reactive Barriers—General
T0511 Metals Removal via Peat—General
T0532 Modified Natural Clays—General
T0542 Mycotech Corporation, Fungal Bioremediation
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0555 Niaski Environmental, Inc., Biopurge
T0556 Niaski Environmental, Inc., BioSparge System
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0628 PTC Enterprises, BioTreat System
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0719 Soil/Sediment Washing—General
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)

T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0756 Supercritical Water Oxidation—General
T0769 Terra Resources, Ltd., Terra Wash Soil Washing
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0794 Thermal Desorption—General
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0818 TVIES, Inc., Soil Washing
T0822 U.S. EPA National Risk Management Research Laboratory, Base-Catalyzed Decomposition
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Advanced Oxidation Process
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0843 University of Cincinnati Department of Civil and Environmental Engineering, Reductive Electrolytic Dechlorination
T0852 U.S. EPA Risk Reduction Engineering Laboratory, Mobile Volume Reduction Unit (VRU)
T0853 UV Technologies, Inc., UV-CATOX Technology
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0877 Weatherly, Inc., AQUA CRITOX
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process

Tetrachlorophenol

T0001 3M Company, 3M Empore Extraction Disk
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0692 SCC Environmental, Micro-Flo
T0822 U.S. EPA National Risk Management Research Laboratory, Base-Catalyzed Decomposition

Trichlorophenol

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0138 Calgon Carbon Corporation, Perox-Pure
T0329 General Atomics, Supercritical Water Oxidation
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0509 Metal-Based Permeable Reactive Barriers—General
T0546 Natural Attenuation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0692 SCC Environmental, Micro-Flo

T0756 Supercritical Water Oxidation—General
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0822 U.S. EPA National Risk Management Research Laboratory, Base-Catalyzed Decomposition
T0829 U.S. Microbics, Inc., Bio-Raptor
T0877 Weatherly, Inc., AQUA CRITOX
T0889 White-Rot Fungus—General

HETEROCYCLIC NITROGEN COMPOUNDS

T0168 CleanSoil, Inc., CleanSoil Process

HETEROCYCLIC OXYGEN COMPOUNDS

T0348 GHEA Associates, Soil Washing Technology

HETEROCYCLIC OXYGEN COMPOUNDS WITH THREE OR MORE RINGS

Dibenzofuran

T0011 Advanced Microbial Solutions, SuperBio
T0161 Chemical Oxidation—General
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0309 Fixed-Bed Soil Biofilters—General
T0329 General Atomics, Supercritical Water Oxidation
T0348 GHEA Associates, Soil Washing Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0756 Supercritical Water Oxidation—General
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0889 White-Rot Fungus—General

Oxygen Heterocycles with Three or More Rings

T0011 Advanced Microbial Solutions, SuperBio
T0161 Chemical Oxidation—General

T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0309 Fixed-Bed Soil Biofilters—General
T0329 General Atomics, Supercritical Water Oxidation
T0348 GHEA Associates, Soil Washing Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0756 Supercritical Water Oxidation—General
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0889 White-Rot Fungus—General

HYDRAZINE DERIVATIVES

Dimethylhydrazine, *N*,*N*; Unsymmetrical Dimethylhydrazine

T0138 Calgon Carbon Corporation, Perox-Pure
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process

Hydrazine Derivatives

T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process

Methylhydrazine; Monomethylhydrazine

T0138 Calgon Carbon Corporation, Perox-Pure
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process

IODINE

T0355 Granular Activated Carbon (GAC)—General
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0536 Molten Salt Oxidation—General
T0543 Naiad Technologies, Inc., RadAway
T0546 Natural Attenuation—General
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP

T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0817 T-Thermal Company, Submerged Quench Incineration

IONIC SPECIES CONTAINING IRON

Ferrocyanide Ion

T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)

IONS CONTAINING PHOSPHORUS

Phosphate

T0011 Advanced Microbial Solutions, SuperBio
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0158 CH2M Hill, Phytoremediation-Based Systems
T0161 Chemical Oxidation—General
T0169 Clemson University, Sintered Ceramic Stabilization
T0178 Constructed Wetlands—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0236 Electrokinetic Remediation—General
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0359 GTS Duratek, DuraMelter
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0543 Naiad Technologies, Inc., RadAway
T0546 Natural Attenuation—General
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0607 Phytoremediation—General
T0644 Recra Environmental, Inc., Alternating Current Electrocoagulation
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0772 Terra Vac, Geochemical Fixation
T0875 Waterloo Barrier, Inc., Waterloo Barrier

IONS CONTAINING SULFUR

Sulfate Ion

T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0107 Biomet Mining Solutions Corporation, Biosulfide Process

T0127 Blast Fracturing—General
T0169 Clemson University, Sintered Ceramic Stabilization
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0230 EET Corporation, Microwaste Waste Solidification
T0236 Electrokinetic Remediation—General
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0329 General Atomics, Supercritical Water Oxidation
T0352 Golder Associates Corporation, Montan Wax Barrier
T0359 GTS Duratek, DuraMelter
T0378 HPT Research, Inc., Ionic State Modification (ISM) Process for the Treatment of Acid Mine Drainage
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0546 Natural Attenuation—General
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0601 Permeable Reactive Barriers (PRBs)—General
T0661 Reverse Osmosis—General
T0668 Rochem Environmental, Inc., Disc Tube
T0756 Supercritical Water Oxidation—General
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0860 Viatec Recovery Systems, Inc., Waste Acid Detoxification and Reclamation
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat

Sulfide Ion

T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0421 InterBio, Hydrobac
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)

IONS WITH NITROGEN

Ammonium Ion; NH_4^+

T0044 Applied Natural Sciences, Inc., TreeMediation
T0178 Constructed Wetlands—General
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0509 Metal-Based Permeable Reactive Barriers—General
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats

T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0601 Permeable Reactive Barriers (PRBs)—General
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0668 Rochem Environmental, Inc., Disc Tube
T0756 Supercritical Water Oxidation—General
T0817 T-Thermal Company, Submerged Quench Incineration
T0829 U.S. Microbics, Inc., Bio-Raptor

Cyanide (CN^-)

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0030 Alternative Technologies for Waste, Inc., TerraSure
T0080 Battelle Memorial Institute, Electroacoustic Dewatering
T0107 Biomet Mining Solutions Corporation, Biosulfide Process
T0113 Bioremediation Service, Inc., AquaPlant Biofilter System
T0131 Brice Environmental Services Corporation (BESCORP), Soil Washing System (BSWS)
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0161 Chemical Oxidation—General
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0235 Electrochemical Treatment of Contaminated Groundwater—General
T0236 Electrokinetic Remediation—General
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0355 Granular Activated Carbon (GAC)—General
T0365 Harding ESE, Inc., Composting
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process In Situ
T0416 Intech One Eighty, White-Rot Fungus
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0500 Maxymillian Technologies, Inc., Thermal Desorption System
T0529 Millgard Corporation, MecTool Remediation System
T0531 Mirage Systems, Inc., ChemChar Process
T0541 MYCELX Technologies Corporation, MYCELX
T0562 North American Technologies Group, Inc., System IV
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0581 Onsite*Ofsite, Inc., Thermochemical Environmental Energy System
T0607 Phytoremediation—General

T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0615 Polymer-Based Solidification/Stabilization—General
T0668 Rochem Environmental, Inc., Disc Tube
T0673 Rotating Biological Contactors—General
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0726 Solidification/Stabilization—General
T0740 Stablex Canada, Inc., Stablex Process
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0769 Terra Resources, Ltd., Terra Wash Soil Washing
T0772 Terra Vac, Geochemical Fixation
T0794 Thermal Desorption—General
T0801 Thermoplastic Stabilization/Solidification—General
T0823 U.S. Filter Corporation, PO*WW*ER Wastewater Treatment System
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Advanced Oxidation Process
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0853 UV Technologies, Inc., UV-CATOX Technology
T0861 Viking Industries, Inc., Acidification–Volatilization and Recovery
T0862 Vortec Corporation, Cyclone Melting System (CMS)
T0864 Walker Process Equipment, EnviroDisc Rotating Biological Contactors
T0872 Water and Slurry Purification Process (WASPP) Corporation, Alternating Current Electrolysis
T0889 White-Rot Fungus—General
T0899 Zenon Environmental Systems, Inc., ZenoGem

Hydrazine

T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0793 Thermal Conversion Corporation, Plasma Energy Recycle and Conversion (PERC)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Advanced Oxidation Process
T0853 UV Technologies, Inc., UV-CATOX Technology

Nitrate (NO_3^-)

T0011 Advanced Microbial Solutions, SuperBio
T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0044 Applied Natural Sciences, Inc., TreeMediation
T0045 Applied Research Associates, Inc., Bioremediation of Perchlorate
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0060 Argonne National Laboratory, Aqueous Biphasic Extraction System
T0061 Argonne National Laboratory, Biocatalytic Destruction of Nitrate
T0086 Battelle Pacific Northwest Laboratory, Vegetable Oil Remediation
T0115 Bioscience, Inc., BIOX Biotreater
T0127 Blast Fracturing—General
T0158 CH2M Hill, Phytoremediation-Based Systems

T0169 Clemson University, Sintered Ceramic Stabilization
T0174 Commodore Separation Technologies, Inc., Supported Liquid Membrane
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0180 Constructed Wetlands for Explosives Contamination—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0230 EET Corporation, Microwaste Waste Solidification
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized-Bed Reactor (GAC FBR) Process
T0236 Electrokinetic Remediation—General
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0262 Envirocare of Utah, Inc., Polyethylene Encapsulation
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0281 Environmental Resources Management Corporation (ERM), Advanced Fluidized Composting (AFC)
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0318 FRX, Inc., Hydraulic Fracturing
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0342 Geo-Microbial Technologies, Inc., Metals Release and Removal from Wastes
T0359 GTS Duratek, DuraMelter
T0384 Hydraulic Fracturing—General
T0392 Idaho National Engineering Laboratory, Biological Destruction of Tank Wastes (BDTW)
T0399 IEG Technologies, Groundwater Circulation Wells (GZB)
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0466 Krudico, Inc., Ion Exchange Resins for Nitrate and Perchlorate
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0474 Lawrence Livermore National Laboratory, Hot-Recycled-Solid (HRS) Retorting Process
T0506 Membran Corporation, Membrane Gas Transfer
T0509 Metal-Based Permeable Reactive Barriers—General
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0531 Mirage Systems, Inc., ChemChar Process
T0533 Molasses Treatment for Bioremediation—General
T0546 Natural Attenuation—General
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0582 Onyx Industrial Services, SOIL*EX
T0586 Pacific Northwest National Laboratory, In Situ Redox Manipulation
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0601 Permeable Reactive Barriers (PRBs)—General
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process

T0627 *Pseudomonas* sp. Strain KC—General
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0668 Rochem Environmental, Inc., Disc Tube
T0673 Rotating Biological Contactors—General
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0702 Selective Environmental Technologies, Inc. (Selentec), Electrochemical Ion Exchange
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0725 Solidification and Immobilization of Radioactive Wastes in Cement—General
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0800 ThermoEnergy Corporation, NitRem
T0860 Viatec Recovery Systems, Inc., Waste Acid Detoxification and Reclamation
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II

IRON

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0020 Aeration Basins—General
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0023 Affinity Water Technologies, Advanced Affinity Chromatography
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0054 Arctech, Inc., Humasorb
T0066 Argonne National Laboratory, Transuranium Extraction (TRUEX) Process
T0072 Atomic Energy of Canada Ltd. (AECL), CHEMIC Technology
T0081 Battelle Memorial Institute, Liquid–Liquid Extraction of Metals (LLX)
T0107 Biomet Mining Solutions Corporation, Biosulfide Process
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0230 EET Corporation, Microwaste Waste Solidification
T0232 Eichrom Industries, Inc., Diphonix
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0279 Environmental Research and Development, Inc., Neutral Process for Heavy-Metals Removal
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation

T0348 GHEA Associates, Soil Washing Technology
T0377 Horsehead Resource Development Company, Inc., Flame Reactor
T0378 HPT Research, Inc., Ionic State Modification (ISM) Process for the Treatment of Acid Mine Drainage
T0382 Humboldt State University, Chitosan Derivative
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0461 Kinit Enterprises, Trozone Soil Remediation System
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0477 Lehigh University, Hybrid Inorganic Solvent HISORB
T0478 Lewis Environmental Services, Inc., Soil-Leaching and Enviro-Clean Technologies
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0517 Metcalf & Eddy, Inc., SOLFIX
T0521 Met-Tech, Inc., Metal Separation by Liquid Ion Exchange
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0536 Molten Salt Oxidation—General
T0540 MSE Technology Applications, Inc., Viscous Barrier Technology
T0560 Normrock Industries, Inc., Amphibex Excavator
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0607 Phytoremediation—General
T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0658 Resource Management and Recovery, AlgaSORB
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0692 SCC Environmental, Micro-Flo
T0696 Science Applications International Corporation, Plasma Hearth Process
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0738 SpinTek Systems, SpinTek
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0773 Terra Vac, Heap Leaching
T0819 U.S. Department of Energy Laboratories, Enhanced Sludge Washing
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0860 Viatec Recovery Systems, Inc., Waste Acid Detoxification and Reclamation
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0887 Westinghouse Savannah River Corporation, Transportable Vitrification System
T0899 Zenon Environmental Systems, Inc., ZenoGem

KETONES

Acetone

T0011 Advanced Microbial Solutions, SuperBio
T0024 Air Stripping—General

T0033 Ambient Engineering, Inc., BIOTON
T0079 BasysTechnologies, Basys Biofilter
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0205 Diversified Remediation Controls, Inc., Turbostripper
T0212 Dual-Phase Extraction—General
T0236 Electrokinetic Remediation—General
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0259 ENSR International Group, Biovault
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0308 First Environment, Inc., FE ACTIVE
T0309 Fixed-Bed Soil Biofilters—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0320 Funderburk & Associates, Solidification Process
T0329 General Atomics, Supercritical Water Oxidation
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0467 KSE, Inc., AIR-II Process
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0494 ManTech Environmental Corporation, CleanOX Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0566 NUCON International, Inc., Brayton Cycle
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0596 Pecan-Based Granular Activated Carbon—General
T0617 PPC Biofilter, Biofiltration Systems

T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0639 R.E. Wright Environmental, Inc., In Situ Bioremediation Treatment System
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0672 Rohm and Haas Company, Ambersorb 600
T0673 Rotating Biological Contactors—General
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0788 Texas A&M University, Low-Pressure Surface Wave Plasma Reactor
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Advanced Oxidation Process
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0864 Walker Process Equipment, EnviroDisc Rotating Biological Contactors
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0891 Williams Environmental, RamSorb-1
T0898 Zapit Technology, Inc., Zapit Processing Unit

Butanone; MEK; Methyl Ethyl Ketone

T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0024 Air Stripping—General
T0115 Bioscience, Inc., BIOX Biotreater
T0126 Bioventing—General
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0205 Diversified Remediation Controls, Inc., Turbostripper
T0259 ENSR International Group, Biovault
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0309 Fixed-Bed Soil Biofilters—General
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0329 General Atomics, Supercritical Water Oxidation
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification

T0344 Geosafe Corporation, In Situ Vitrification
T0355 Granular Activated Carbon (GAC)—General
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0384 Hydraulic Fracturing—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0449 IT Corporation, Thermal Desorption
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0494 ManTech Environmental Corporation, CleanOX Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0529 Millgard Corporation, MecTool Remediation System
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0617 PPC Biofilter, Biofiltration Systems
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0639 R.E. Wright Environmental, Inc., In Situ Bioremediation Treatment System
T0672 Rohm and Haas Company, Ambersorb 600
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0756 Supercritical Water Oxidation—General
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0855 Vapor-Phase Biofiltration—General
T0891 Williams Environmental, RamSorb-1

Cyclohexanone

T0161 Chemical Oxidation—General
T0355 Granular Activated Carbon (GAC)—General
T0566 NUCON International, Inc., Brayton Cycle
T0775 Terra Vac, Inc., Dual-Vacuum Extraction

T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction

Isophorone

T0001 3M Company, 3M Empore Extraction Disk
T0138 Calgon Carbon Corporation, Perox-Pure
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0794 Thermal Desorption—General
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation

Isopropylacetone; Methyl Isobutyl Ketone; Hexone; 4-Methyl-2-pentanone

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0054 Arctech, Inc., Humasorb
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0259 ENSR International Group, Biovault
T0289 EnviroSep, Inc., Thick-Film Absorption (TFA)
T0309 Fixed-Bed Soil Biofilters—General
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0617 PPC Biofilter, Biofiltration Systems
T0628 PTC Enterprises, BioTreat System
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0774 Terra Vac, Inc., Biovac
T0779 Terra Vac, Inc., Vacuum Extraction
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)

Ketones

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0033 Ambient Engineering, Inc., BIOTON
T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0054 Arctech, Inc., Humasorb
T0079 BasysTechnologies, Basys Biofilter

T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0101 Bio-Genesis Technologies, Aerobic Biotreatment System (ABS)
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0115 Bioscience, Inc., BIOX Biotreater
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0205 Diversified Remediation Controls, Inc., Turbostripper
T0212 Dual-Phase Extraction—General
T0236 Electrokinetic Remediation—General
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0259 ENSR International Group, Biovault
T0267 Envirogen, Inc., Spartech
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0289 EnviroSep, Inc., Thick-Film Absorption (TFA)
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0308 First Environment, Inc., FE ACTIVE
T0309 Fixed-Bed Soil Biofilters—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0320 Funderburk & Associates, Solidification Process
T0329 General Atomics, Supercritical Water Oxidation
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process

T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0449 IT Corporation, Thermal Desorption
T0467 KSE, Inc., AIR-II Process
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0494 ManTech Environmental Corporation, CleanOX Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0541 MYCELX Technologies Corporation, MYCELX
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0566 NUCON International, Inc., Brayton Cycle
T0581 Onsite*Ofsite, Inc., Thermochemical Environmental Energy System
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0596 Pecan-Based Granular Activated Carbon—General
T0599 PerkinElmer, Inc., NoVOCs
T0617 PPC Biofilter, Biofiltration Systems
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0628 PTC Enterprises, BioTreat System
T0637 R.C. Costello and Associates, Inc., Actopentin Biomass Filter
T0639 R.E. Wright Environmental, Inc., In Situ Bioremediation Treatment System
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0672 Rohm and Haas Company, Ambersorb 600
T0673 Rotating Biological Contactors—General
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0778 Terra Vac, Inc., Sparge VAC

T0779 Terra Vac, Inc., Vacuum Extraction
T0788 Texas A&M University, Low-Pressure Surface Wave Plasma Reactor
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Advanced Oxidation Process
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0864 Walker Process Equipment, EnviroDisc Rotating Biological Contactors
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0891 Williams Environmental, RamSorb-1
T0898 Zapit Technology, Inc., Zapit Processing Unit

LANTHANIDES

T0005 Active Environmental Technologies, Inc., TechXtract
T0066 Argonne National Laboratory, Transuranium Extraction (TRUEX) Process
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0200 Delphi Research, Inc., DETOX
T0232 Eichrom Industries, Inc., Diphonix
T0291 EnviroSource Technologies, Inc., Super Detox Process
T0531 Mirage Systems, Inc., ChemChar Process
T0535 Molten Metal Technology, Inc., Quantum Catalytic Extraction Process (Q-CEP)
T0536 Molten Salt Oxidation—General
T0569 Oak Ridge National Laboratory, Glass Material Oxidation and Dissolution System
T0607 Phytoremediation—General
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0742 Starmet Corporation, RocTec Stabilization
T0756 Supercritical Water Oxidation—General
T0808 Toledo Engineering Company, Inc., High-Temperature Joule-Heated Vitrification
T0819 U.S. Department of Energy Laboratories, Enhanced Sludge Washing
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0862 Vortec Corporation, Cyclone Melting System (CMS)

LEAD

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0037 American Soil Technologies, Inc., CT-500 Chemical Stabilization System
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0042 Applied Environmental Services, Inc., Asphaltic Metals Stabilization
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0053 ARCADIS Geraghty and Miller, Inc., STRATEX (Stratified Temperature Extractor)

T0054 Arctech, Inc., Humasorb
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0066 Argonne National Laboratory, Transuranium Extraction (TRUEX) Process
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0080 Battelle Memorial Institute, Electroacoustic Dewatering
T0090 Beco Engineering Company, Alka/Sorb
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0118 Biosorption—General
T0124 BioTrol, Inc., Soil Washing Technology
T0131 Brice Environmental Services Corporation (BESCORP), Soil Washing System (BSWS)
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0149 Cement-Based Stabilization/Solidification—General
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0162 Chemical Precipitation of Metals—General
T0169 Clemson University, Sintered Ceramic Stabilization
T0176 Concurrent Technologies Corporation, Acid Extraction Treatment System (AETS)
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0190 Cunningham-Davis Environmental (CDE Resources, Inc.), CDE Soil Recycling
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0200 Delphi Research, Inc., DETOX
T0207 Doe Run Company, TERRAMET Heavy-Metal Removal Technology
T0214 DuPont/Oberlin, Microfiltration Technology
T0218 Dynaphore, Inc., Forager Sponge Technology
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0230 EET Corporation, Microwaste Waste Solidification
T0232 Eichrom Industries, Inc., Diphonix
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0262 Envirocare of Utah, Inc., Polyethylene Encapsulation
T0276 Environmental Recycling, L.L.C., Asphalt Stabilized Base/Engineered Backfill
T0279 Environmental Research and Development, Inc., Neutral Process for Heavy-Metals Removal
T0280 Environmental Research and Development, Inc., Ice Electrode
T0285 Environmental Technology (U.S.), Inc., TR-Detox
T0291 EnviroSource Technologies, Inc., Super Detox Process
T0292 EnviroWall, Inc., EnviroWall Barrier
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0304 F2 Associates, Inc., Laser Ablation
T0306 Ferro Corporation, Waste Vitrification through Electric Melting
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0313 Forrester Environmental Services, Inc., Heavy-Metal Stabilization

T0320 Funderburk & Associates, Solidification Process
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0348 GHEA Associates, Soil Washing Technology
T0355 Granular Activated Carbon (GAC)—General
T0359 GTS Duratek, DuraMelter
T0373 Horizontal Drilling—General
T0377 Horsehead Resource Development Company, Inc., Flame Reactor
T0378 HPT Research, Inc., Ionic State Modification (ISM) Process for the Treatment of Acid Mine Drainage
T0382 Humboldt State University, Chitosan Derivative
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0403 IM-TECH, Solidification/Stabilization Process
T0410 Institute of Gas Technology, AGGCOM
T0418 Integrated Chemistries, Inc., Metraxt
T0426 International Environmental Trading Company, Inc., Metals Extraction and Recycling System
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0450 IT Corporation, Thermal Destruction Unit
T0452 Joule-Heated Vitrification—General
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0477 Lehigh University, Hybrid Inorganic Solvent HISORB
T0478 Lewis Environmental Services, Inc., Soil-Leaching and Enviro-Clean Technologies
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0486 Los Alamos National Laboratory, Uranium Heap Leaching Technology
T0488 Lynntech, Inc., Electrokinetic Remediation of Contaminated Soil
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0496 MARCOR Remediation, Inc., Advanced Chemical Treatment
T0509 Metal-Based Permeable Reactive Barriers—General
T0510 Metals Recovery, Inc., Metals Leaching
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0517 Metcalf & Eddy, Inc., SOLFIX
T0518 Met-Chem, Metal Kleen A
T0519 Met-Chem, Metal Kleen B (MCB)
T0521 Met-Tech, Inc., Metal Separation by Liquid Ion Exchange
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0529 Millgard Corporation, MecTool Remediation System
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General

T0541 MYCELX Technologies Corporation, MYCELX
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0557 NoChar, Inc., Leadbond
T0560 Normrock Industries, Inc., Amphibex Excavator
T0562 North American Technologies Group, Inc., System IV
T0582 Onyx Industrial Services, SOIL*EX
T0583 Oregon State University, Chitosan Beads
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0594 PEAT, Inc., Thermal Destruction and Recovery
T0596 Pecan-Based Granular Activated Carbon—General
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0601 Permeable Reactive Barriers (PRBs)—General
T0605 Physical Sciences, Inc., Metals Immobilization and Decontamination of Aggregate Solids (MeIDAS)
T0607 Phytoremediation—General
T0608 Phytoremediation: Hyperaccumulation—General
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0613 Plasma Vitrification—General
T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System
T0615 Polymer-Based Solidification/Stabilization—General
T0616 Pozzolanic Solidification/Stabilization—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0624 Proactive Applied Solutions Corporation, LEADX
T0644 Recra Environmental, Inc., Alternating Current Electrocoagulation
T0657 Resonant Shock Compaction, L.L.C., Resonant Shock Compaction
T0658 Resource Management and Recovery, AlgaSORB
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0667 RMT, Inc., Metal Treatment Technology (MTTTM)
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0692 SCC Environmental, Micro-Flo
T0696 Science Applications International Corporation, Plasma Hearth Process
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0714 Smith Environmental Corporation, Battery Waste Treatment Process
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0719 Soil/Sediment Washing—General
T0724 Soil Technology, Inc., Soil Washing Treatability Study Unit
T0726 Solidification/Stabilization—General
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0730 Solucorp Industries, Ltd., Molecular Bonding System
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0741 Stark Encapsulation, Inc., METLCAP Chemical Cement
T0742 Starmet Corporation, RocTec Stabilization
T0746 STC Remediation, Inc., Solidification/Stabilization Technology

T0755 Supercritical Carbon Dioxide Extraction—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0763 Tallon, Inc., Virtokele
T0765 Technology Scientific, Ltd., Flow Consecutor Technology (FCT)
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0772 Terra Vac, Geochemical Fixation
T0773 Terra Vac, Heap Leaching
T0781 TerraFix, L.L.C., TerraFix
T0789 Texilla Environmental, Inc., Synthetic Mineral Immobilization Technology (SMITE)
T0794 Thermal Desorption—General
T0801 Thermoplastic Stabilization/Solidification—General
T0810 Toxic Environmental Control Systems, Inc., Electrode-Assisted Soil Washing
T0815 Trigon Group, L.L.C., ARCHON In Situ Mixer
T0817 T-Thermal Company, Submerged Quench Incineration
T0818 TVIES, Inc., Soil Washing
T0821 U.S. EPA and IT Corporation, Debris Washing System
T0824 U.S. Filter Corporation, WESPHix
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0830 U.S. Naval Academy, Air Classifier with Removal of Metals from Soil
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0847 University of New South Wales, Upflow Washing
T0849 University of Washington, Metals Treatment by Adsorptive Filtration
T0850 UOP Ionsiv, IE-911 Ion Exchange Resins
T0857 Vendor Unknown, Calochroma Soil Washing
T0862 Vortec Corporation, Cyclone Melting System (CMS)
T0871 WASTECH, Inc., Solidification and Stabilization
T0874 Water Technology International Corporation, Self-Sealing/Self-Healing Barrier (SS/SH)
T0879 Western Environmental Science and Technology (WEST), Soil Washing of Lead-Contaminated Soil
T0880 Western Product Recovery Group, Inc., Coordinate Chemical Bonding and Adsorption (CCBA) Process
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0887 Westinghouse Savannah River Corporation, Transportable Vitrification System
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0899 Zenon Environmental Systems, Inc., ZenoGem

LEAD COMPOUNDS

Lead Compounds

T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0091 BenCHEM, Inc., Soil Washing Technology
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0149 Cement-Based Stabilization/Solidification—General
T0161 Chemical Oxidation—General
T0236 Electrokinetic Remediation—General
T0313 Forrester Environmental Services, Inc., Heavy-Metal Stabilization
T0488 Lynntech, Inc., Electrokinetic Remediation of Contaminated Soil
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process

T0615 Polymer-Based Solidification/Stabilization—General
T0616 Pozzolanic Solidification/Stabilization—General
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0726 Solidification/Stabilization—General
T0801 Thermoplastic Stabilization/Solidification—General
T0818 TVIES, Inc., Soil Washing

Tetraethyl Lead

T0091 BenCHEM, Inc., Soil Washing Technology
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0818 TVIES, Inc., Soil Washing

LITHIUM

T0236 Electrokinetic Remediation—General
T0344 Geosafe Corporation, In Situ Vitrification
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0756 Supercritical Water Oxidation—General

MAGNESIUM

T0001 3M Company, 3M Empore Extraction Disk
T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0054 Arctech, Inc., Humasorb
T0090 Beco Engineering Company, Alka/Sorb
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0158 CH2M Hill, Phytoremediation-Based Systems
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0230 EET Corporation, Microwaste Waste Solidification
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0355 Granular Activated Carbon (GAC)—General
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0596 Pecan-Based Granular Activated Carbon—General
T0607 Phytoremediation—General
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0756 Supercritical Water Oxidation—General

MANGANESE

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0023 Affinity Water Technologies, Advanced Affinity Chromatography
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0054 Arctech, Inc., Humasorb
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0155 CFX Corporation, CFX MiniFix
T0162 Chemical Precipitation of Metals—General
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0218 Dynaphore, Inc., Forager Sponge Technology
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0232 Eichrom Industries, Inc., Diphonix
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0378 HPT Research, Inc., Ionic State Modification (ISM) Process for the Treatment of Acid Mine Drainage
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0509 Metal-Based Permeable Reactive Barriers—General
T0518 Met-Chem, Metal Kleen A
T0519 Met-Chem, Metal Kleen B (MCB)
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0535 Molten Metal Technology, Inc., Quantum Catalytic Extraction Process (Q-CEP)
T0536 Molten Salt Oxidation—General
T0540 MSE Technology Applications, Inc., Viscous Barrier Technology
T0546 Natural Attenuation—General
T0560 Normrock Industries, Inc., Amphibex Excavator
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0601 Permeable Reactive Barriers (PRBs)—General
T0608 Phytoremediation: Hyperaccumulation—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0658 Resource Management and Recovery, AlgaSORB
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0692 SCC Environmental, Micro-Flo
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0773 Terra Vac, Heap Leaching
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)

MERCURY

T0005 Active Environmental Technologies, Inc., TechXtract
T0015 Advanced Recovery Systems, Inc., DeHg
T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0023 Affinity Water Technologies, Advanced Affinity Chromatography
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0041 AP Technologies, Inc., Mercrobes Mercury Reduction Technology
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0053 ARCADIS Geraghty and Miller, Inc., STRATEX (Stratified Temperature Extractor)
T0054 Arctech, Inc., Humasorb
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0066 Argonne National Laboratory, Transuranium Extraction (TRUEX) Process
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0080 Battelle Memorial Institute, Electroacoustic Dewatering
T0082 Battelle Memorial Institute, Universal Demercurization Process (UNIDEMP)
T0090 Beco Engineering Company, Alka/Sorb
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0103 Biogenie SRDC, Inc., Treatment Process for Mercury-Contaminated Soil
T0135 Calgon Carbon Corporation, Activated Carbon
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0162 Chemical Precipitation of Metals—General
T0169 Clemson University, Sintered Ceramic Stabilization
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0200 Delphi Research, Inc., DETOX
T0204 Distillation—General
T0207 Doe Run Company, TERRAMET Heavy-Metal Removal Technology
T0218 Dynaphore, Inc., Forager Sponge Technology
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0232 Eichrom Industries, Inc., Diphonix
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0279 Environmental Research and Development, Inc., Neutral Process for Heavy-Metals Removal
T0292 EnviroWall, Inc., EnviroWall Barrier
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0313 Forrester Environmental Services, Inc., Heavy-Metal Stabilization
T0320 Funderburk & Associates, Solidification Process
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0359 GTS Duratek, DuraMelter
T0373 Horizontal Drilling—General
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins

T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0426 International Environmental Trading Company, Inc., Metals Extraction and Recycling System
T0428 International Landmark Environmental, Inc., Diatomite
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0449 IT Corporation, Thermal Desorption
T0450 IT Corporation, Thermal Destruction Unit
T0452 Joule-Heated Vitrification—General
T0461 Kinit Enterprises, Trozone Soil Remediation System
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0478 Lewis Environmental Services, Inc., Soil-Leaching and Enviro-Clean Technologies
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0508 Mercury Recovery Services, Inc., Mercury Removal/Recovery Process
T0510 Metals Recovery, Inc., Metals Leaching
T0514 Metcalf & Eddy, Inc., GEMEP
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0518 Met-Chem, Metal Kleen A
T0519 Met-Chem, Metal Kleen B (MCB)
T0531 Mirage Systems, Inc., ChemChar Process
T0533 Molasses Treatment for Bioremediation—General
T0539 Mountain States R&D International, Inc., MSRDI Combination Technology Mercury Treatment System
T0541 MYCELX Technologies Corporation, MYCELX
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0559 NORIT, N.V., Porta-PAC
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0572 Oak Ridge National Laboratory, Mercury Removal by Reactive Leaching
T0583 Oregon State University, Chitosan Beads
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0594 PEAT, Inc., Thermal Destruction and Recovery
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0604 Philip Environmental Services Corporation, Thermal Recycling System
T0607 Phytoremediation—General
T0608 Phytoremediation: Hyperaccumulation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0613 Plasma Vitrification—General
T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0658 Resource Management and Recovery, AlgaSORB
T0667 RMT, Inc., Metal Treatment Technology (MTTTM)
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0696 Science Applications International Corporation, Plasma Hearth Process

T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0719 Soil/Sediment Washing—General
T0723 Soil Technology, Inc., Remediation Technologies Using Electrolytically Produced Water
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0729 Solucorp Industries, Ltd., Mercon
T0730 Solucorp Industries, Ltd., Molecular Bonding System
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0741 Stark Encapsulation, Inc., METLCAP Chemical Cement
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0763 Tallon, Inc., Virtokele
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0773 Terra Vac, Heap Leaching
T0779 Terra Vac, Inc., Vacuum Extraction
T0789 Texilla Environmental, Inc., Synthetic Mineral Immobilization Technology (SMITE)
T0791 The Chlorine Institute, Inc., Thermal Desorption (Mercury Contamination)
T0794 Thermal Desorption—General
T0817 T-Thermal Company, Submerged Quench Incineration
T0818 TVIES, Inc., Soil Washing
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0893 WRS Infrastructure & Environmental, Inc., Thermal Desorption Unit
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0899 Zenon Environmental Systems, Inc., ZenoGem

MOLYBDENUM

T0023 Affinity Water Technologies, Advanced Affinity Chromatography
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0235 Electrochemical Treatment of Contaminated Groundwater—General
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0338 Geo-Microbial Technologies, Inc., Catalyst Clean-Up
T0344 Geosafe Corporation, In Situ Vitrification
T0443 IT Corporation, In Situ Geochemical Fixation
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0509 Metal-Based Permeable Reactive Barriers—General
T0510 Metals Recovery, Inc., Metals Leaching
T0518 Met-Chem, Metal Kleen A
T0519 Met-Chem, Metal Kleen B (MCB)
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0601 Permeable Reactive Barriers (PRBs)—General
T0692 SCC Environmental, Micro-Flo
T0704 Selective Environmental Technologies, Inc., MAG*SEP

MONOHYDRIC PHENOLS

Monohydric Phenols

T0001 3M Company, 3M Empore Extraction Disk
T0002 7-7, Inc., Liquefication Process
T0011 Advanced Microbial Solutions, SuperBio
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0114 Bioremediation Technology Services, Inc., BTS Method
T0115 Bioscience, Inc., BIOX Biotreater
T0126 Bioventing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0161 Chemical Oxidation—General
T0165 Cherokee Environmental Group, The Bio-Solution
T0178 Constructed Wetlands—General
T0185 Corrpro Companies Inc., Electroremediation
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0256 Ensite, Inc., SafeSoil
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0300 ETUS, Inc., Enhanced Bioremediation
T0320 Funderburk & Associates, Solidification Process
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0423 InterBio, Phenobac
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0449 IT Corporation, Thermal Desorption
T0454 KAL CON Environmental Services, Thermal Desorption
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0495 Maple Engineering Services, Inc., Biopur
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0546 Natural Attenuation—General
T0581 Onsite*Ofsite, Inc., Thermochemical Environmental Energy System
T0607 Phytoremediation—General
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0617 PPC Biofilter, Biofiltration Systems

T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0719 Soil/Sediment Washing—General
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0750 Stevens Institute of Technology, Trench Bio-Sparge
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0768 Tekno Associates, Biolift
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0823 U.S. Filter Corporation, PO*WW*ER Wastewater Treatment System
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, Advanced Oxidation Process
T0835 Umpqua Research Company, Low-Temperature Aqueous Phase Catalytic Oxidation
T0853 UV Technologies, Inc., UV-CATOX Technology
T0877 Weatherly, Inc., AQUA CRITOX
T0891 Williams Environmental, RamSorb-1
T0896 Yellowstone Environmental Science, Inc. (YES) Biocat II

Phenol

T0001 3M Company, 3M Empore Extraction Disk
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0114 Bioremediation Technology Services, Inc., BTS Method
T0115 Bioscience, Inc., BIOX Biotreater
T0126 Bioventing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0161 Chemical Oxidation—General
T0178 Constructed Wetlands—General
T0185 Corrpro Companies Inc., Electroremediation
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0236 Electrokinetic Remediation—General

T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0300 ETUS, Inc., Enhanced Bioremediation
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0449 IT Corporation, Thermal Desorption
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0495 Maple Engineering Services, Inc., Biopur
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0581 Onsite*Ofsite, Inc., Thermochemical Environmental Energy System
T0607 Phytoremediation—General
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0617 PPC Biofilter, Biofiltration Systems
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0719 Soil/Sediment Washing—General
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0750 Stevens Institute of Technology, Trench Bio-Sparge
T0755 Supercritical Carbon Dioxide Extraction—General
T0768 Tekno Associates, Biolift
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0823 U.S. Filter Corporation, PO*WW*ER Wastewater Treatment System
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0835 Umpqua Research Company, Low-Temperature Aqueous-Phase Catalytic Oxidation
T0853 UV Technologies, Inc., UV-CATOX Technology
T0891 Williams Environmental, RamSorb-1

Phenol, Dimethyl; Xylenols

T0011 Advanced Microbial Solutions, SuperBio
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation

T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)

Phenol, Methyl; Cresols; Methyl Phenol

T0001 3M Company, 3M Empore Extraction Disk
T0002 7-7, Inc., Liquefication Process
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0126 Bioventing—General
T0135 Calgon Carbon Corporation, Activated Carbon
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0165 Cherokee Environmental Group, The Bio-Solution
T0178 Constructed Wetlands—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0256 Ensite, Inc., SafeSoil
T0320 Funderburk & Associates, Solidification Process
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0423 InterBio, Phenobac
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0449 IT Corporation, Thermal Desorption
T0454 KAL CON Environmental Services, Thermal Desorption
T0546 Natural Attenuation—General
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0794 Thermal Desorption—General
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0853 UV Technologies, Inc., UV-CATOX Technology
T0877 Weatherly, Inc., AQUA CRITOX
T0891 Williams Environmental, RamSorb-1
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II

NICKEL

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0015 Advanced Recovery Systems, Inc., DeHg
T0016 Advanced Separation Technologies, Inc., ISEP Continuous Contactor
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0023 Affinity Water Technologies, Advanced Affinity Chromatography

T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0054 Arctech, Inc., Humasorb
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0081 Battelle Memorial Institute, Liquid–Liquid Extraction of Metals (LLX)
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0149 Cement-Based Stabilization/Solidification—General
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0162 Chemical Precipitation of Metals—General
T0164 ChemPete, Inc., Bioremediation
T0169 Clemson University, Sintered Ceramic Stabilization
T0174 Commodore Separation Technologies, Inc., Supported Liquid Membrane
T0176 Concurrent Technologies Corporation, Acid Extraction Treatment System (AETS)
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0200 Delphi Research, Inc., DETOX
T0207 Doe Run Company, TERRAMET Heavy-Metal Removal Technology
T0214 DuPont/Oberlin, Microfiltration Technology
T0218 Dynaphore, Inc., Forager Sponge Technology
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0230 EET Corporation, Microwaste Waste Solidification
T0232 Eichrom Industries, Inc., Diphonix
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0279 Environmental Research and Development, Inc., Neutral Process for Heavy Metals Removal
T0285 Environmental Technology (U.S.), Inc., TR-Detox
T0291 EnviroSource Technologies, Inc., Super Detox Process
T0292 EnviroWall, Inc., EnviroWall Barrier
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0301 Evaporation for Wastewater Treatment—General
T0306 Ferro Corporation, Waste Vitrification through Electric Melting
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0320 Funderburk & Associates, Solidification Process
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0338 Geo-Microbial Technologies, Inc., Catalyst Clean-Up
T0344 Geosafe Corporation, In Situ Vitrification
T0355 Granular Activated Carbon (GAC)—General
T0359 GTS Duratek, DuraMelter
T0377 Horsehead Resource Development Company, Inc., Flame Reactor
T0378 HPT Research, Inc., Ionic State Modification (ISM) Process for the Treatment of Acid Mine Drainage

T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0426 International Environmental Trading Company, Inc., Metals Extraction and Recycling System
T0452 Joule-Heated Vitrification—General
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0477 Lehigh University, Hybrid Inorganic Solvent HISORB
T0478 Lewis Environmental Services, Inc., Soil-Leaching and Enviro-Clean Technologies
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0488 Lynntech, Inc., Electrokinetic Remediation of Contaminated Soil
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0510 Metals Recovery, Inc., Metals Leaching
T0511 Metals Removal Via Peat—General
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0517 Metcalf & Eddy, Inc., SOLFIX
T0518 Met-Chem, Metal Kleen A
T0519 Met-Chem, Metal Kleen B (MCB)
T0521 Met-Tech, Inc., Metal Separation by Liquid Ion Exchange
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0529 Millgard Corporation, MecTool Remediation System
T0531 Mirage Systems, Inc., ChemChar Process
T0533 Molasses Treatment for Bioremediation—General
T0535 Molten Metal Technology, Inc., Quantum Catalytic Extraction Process (Q-CEP)
T0536 Molten Salt Oxidation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0546 Natural Attenuation—General
T0560 Normrock Industries, Inc., Amphibex Excavator
T0562 North American Technologies Group, Inc., System IV
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0583 Oregon State University, Chitosan Beads
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0596 Pecan-Based Granular Activated Carbon—General
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0608 Phytoremediation: Hyperaccumulation—General
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0613 Plasma Vitrification—General
T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System
T0615 Polymer-Based Solidification/Stabilization—General
T0616 Pozzolanic Solidification/Stabilization—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0644 Recra Environmental, Inc., Alternating Current Electrocoagulation
T0658 Resource Management and Recovery, AlgaSORB
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0661 Reverse Osmosis—General
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0692 SCC Environmental, Micro-Flo

T0696 Science Applications International Corporation, Plasma Hearth Process
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0726 Solidification/Stabilization—General
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0730 Solucorp Industries, Ltd., Molecular Bonding System
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0763 Tallon, Inc., Virtokele
T0799 ThermoChem, Inc., PulseEnhanced Steam Reformer
T0801 Thermoplastic Stabilization/Solidification—General
T0808 Toledo Engineering Company, Inc., High-Temperature Joule-Heated Vitrification
T0821 U.S. EPA and IT Corporation, Debris Washing System
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0849 University of Washington, Metals Treatment by Adsorptive Filtration
T0862 Vortec Corporation, Cyclone Melting System (CMS)
T0874 Water Technology International Corporation, Self-Sealing/Self-Healing Barrier (SS/SH)
T0880 Western Product Recovery Group, Inc., Coordinate Chemical Bonding and Adsorption (CCBA) Process
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0899 Zenon Environmental Systems, Inc., ZenoGem

NITROGEN COMPOUNDS

Ammonia

T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0127 Blast Fracturing—General
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0158 CH2M Hill, Phytoremediation-Based Systems
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0205 Diversified Remediation Controls, Inc., Turbostripper
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0329 General Atomics, Supercritical Water Oxidation
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0467 KSE, Inc., AIR-II Process
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0607 Phytoremediation—General
T0617 PPC Biofilter, Biofiltration Systems
T0637 R.C. Costello and Associates, Inc., Actopentin Biomass Filter
T0668 Rochem Environmental, Inc., Disc Tube
T0673 Rotating Biological Contactors—General
T0756 Supercritical Water Oxidation—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

T0800 ThermoEnergy Corporation, NitRem
T0802 ThermoRetec, Microbial Fence
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0855 Vapor-Phase Biofiltration—General
T0864 Walker Process Equipment, EnviroDisc Rotating Biological Contactors
T0899 Zenon Environmental Systems, Inc., ZenoGem

Nitrogen Trifluoride

T0032 Alzeta Corporation, EDGE Thermal Processing Units
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma

NITROPHENOLIC COMPOUNDS

T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0161 Chemical Oxidation—General
T0236 Electrokinetic Remediation—General
T0395 Idaho Research Foundation, Inc., and White Shield, Inc., Simplot Anaerobic Biological Remediation (SABRE)

NITROPHENOLS

Nitrophenol, 4; Nitrophenol, *p*

T0001 3M Company, 3M Empore Extraction Disk
T0114 Bioremediation Technology Services, Inc., BTS Method
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0236 Electrokinetic Remediation—General
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0537 Monsanto Company, Lasagna
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation

Nitrophenols

T0001 3M Company, 3M Empore Extraction Disk
T0114 Bioremediation Technology Services, Inc., BTS Method
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0161 Chemical Oxidation—General
T0200 Delphi Research, Inc., DETOX
T0236 Electrokinetic Remediation—General
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation

T0395 Idaho Research Foundation, Inc., and White Shield, Inc., Simplot Anaerobic Biological Remediation (SABRE)
T0537 Monsanto Company, Lasagna
T0546 Natural Attenuation—General
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process

Picric Acid; Trinitrophenol

T0200 Delphi Research, Inc., DETOX
T0546 Natural Attenuation—General
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants

NITROSAMINES

T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0817 T-Thermal Company, Submerged Quench Incineration

NONCYCLIC ALIPHATIC OR AROMATIC ETHERS

Diethyl Ether

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0756 Supercritical Water Oxidation—General
T0855 Vapor-Phase Biofiltration—General

Methyl *tert*-Butyl Ether; MTBE; Methyl Tertiary Butyl Ether

T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0096 BioEnviroTech, Inc., BioPetro
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0161 Chemical Oxidation—General
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0205 Diversified Remediation Controls, Inc., Turbostripper
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)

T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0355 Granular Activated Carbon (GAC)—General
T0356 Groundwater Recovery Systems, Inc., OXY 1
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0494 ManTech Environmental Corporation, CleanOX Process
T0541 MYCELX Technologies Corporation, MYCELX
T0546 Natural Attenuation—General
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0577 On-Site Technologies, Modular Interchangeable Treatment System (MITS)
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0776 Terra Vac, Inc., Oxy Vac
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0829 U.S. Microbics, Inc., Bio-Raptor
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0855 Vapor-Phase Biofiltration—General

Noncyclic Aliphatic or Aromatic Ethers

T0011 Advanced Microbial Solutions, SuperBio
T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0096 BioEnviroTech, Inc., BioPetro
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0161 Chemical Oxidation—General
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0205 Diversified Remediation Controls, Inc., Turbostripper
T0277 Environmental Remediation Consultants, Inc., Biointegration

T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0355 Granular Activated Carbon (GAC)—General
T0356 Groundwater Recovery Systems, Inc., OXY 1
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0494 ManTech Environmental Corporation, CleanOX Process
T0541 MYCELX Technologies Corporation, MYCELX
T0546 Natural Attenuation—General
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0577 On Site Technologies, Modular Interchangeable Treatment System (MITS)
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0756 Supercritical Water Oxidation—General
T0776 Terra Vac, Inc., Oxy Vac
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0891 Williams Environmental, RamSorb-1

Tetrahydrofuran

T0011 Advanced Microbial Solutions, SuperBio
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General

T0853 UV Technologies, Inc., UV-CATOX Technology
T0891 Williams Environmental, RamSorb-1

ORGANOPHOSPHONATES

Diisopropyl Methyl Phosphonate; DIMP

T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0817 T-Thermal Company, Submerged Quench Incineration
T0833 Ultraviolet Oxidation (UV/Oxidation)—General

Organophosphonates

T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0321 Fungi Perfecti, Mycova Mycoremediation and Mycofiltration
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0817 T-Thermal Company, Submerged Quench Incineration
T0833 Ultraviolet Oxidation (UV/Oxidation)—General

ORGANOPHOSPHORUS COMPOUNDS

T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0321 Fungi Perfecti, Mycova Mycoremediation and Mycofiltration
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0794 Thermal Desorption—General
T0817 T-Thermal Company, Submerged Quench Incineration

ORGANOSULFUR COMPOUNDS WITH OTHER FUNCTIONAL GROUPS

Endosulfan

T0001 3M Company, 3M Empore Extraction Disk
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0755 Supercritical Carbon Dioxide Extraction—General
T0794 Thermal Desorption—General

Organosulfur Compounds with Other Functional Groups

T0001 3M Company, 3M Empore Extraction Disk
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0755 Supercritical Carbon Dioxide Extraction—General
T0794 Thermal Desorption—General

OTHER NITROPHENOLS

Dinoseb; *sec*-Butyl Dinitrophenol; Dinitrophenol, 4,6-*sec*-Butyl

T0114 Bioremediation Technology Services, Inc., BTS Method
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0355 Granular Activated Carbon (GAC)—General
T0395 Idaho Research Foundation, Inc., and White Shield, Inc., Simplot Anaerobic Biological Remediation (SABRE)
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit

Other Nitrophenols

T0114 Bioremediation Technology Services, Inc., BTS Method
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0355 Granular Activated Carbon (GAC)—General
T0395 Idaho Research Foundation, Inc., and White Shield, Inc., Simplot Anaerobic Biological Remediation (SABRE)
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit

PESTICIDES

Pesticides/Herbicides

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0010 Advanced Manufacturing and Development, Inc., Advanced Bio-Gest System
T0011 Advanced Microbial Solutions, SuperBio
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0044 Applied Natural Sciences, Inc., TreeMediation
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0055 Arctech, Inc., Bioremediation—Solid Phase
T0056 Arctech, Inc., Light-Activated Reduction of Chemicals (LARC)
T0067 Ariel Industries, Inc., Ariel SST Low-Temperature Thermal Desorber
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0075 B & S Research, Inc., B&S Achieve-B&S Industrial
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process

T0100 BioGenesis Enterprises, Inc., Soil Remediation and Cleaning Products
T0101 Bio-Genesis Technologies, Aerobic Biotreatment System (ABS)
T0108 Biomin, Inc., Organoclay
T0114 Bioremediation Technology Services, Inc., BTS Method
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0143 Carson Environmental, Low-Temperature Oxidation
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0178 Constructed Wetlands—General
T0186 Cosolvent Flushing—General
T0202 Detox Industries, Inc., DETOX Process
T0204 Distillation—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0266 Envirogen, Inc., Solid Organic Phase Extraction (SoPE)
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0299 ETG Environmental, Inc., Thermo-O-Detox Medium-Temperature Thermal Desorption (MTTD)
T0300 ETUS, Inc., Enhanced Bioremediation
T0303 Extraksol (vendor unknown)
T0309 Fixed-Bed Soil Biofilters—General
T0321 Fungi Perfecti, Mycova Mycoremediation and Mycofiltration
T0323 G.E.M., Inc., Chemical Treatment
T0325 Galson Remediation Corporation, APEG-PLUS Process
T0327 General Atomics, Circulating Bed Combustor (CBC)
T0329 General Atomics, Supercritical Water Oxidation

T0333	Geo-Cleanse International, Inc., Geo-Cleanse Process
T0334	Geo-Con Inc., Shallow Soil Mixing/Thermally Enhanced Vapor Extraction
T0343	Georgia Institute of Technology, Construction Research Center In Situ Plasma Vitrification
T0344	Geosafe Corporation, In Situ Vitrification
T0348	GHEA Associates, Soil Washing Technology
T0354	Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355	Granular Activated Carbon (GAC)—General
T0360	H&H Eco Systems, Inc., Microenfractionator
T0361	H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0365	Harding ESE, Inc., Composting
T0371	High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372	Hi-Point Industries, Ltd., Oclansorb
T0376	Horner & Company, Max Bac
T0379	Hrubetz Environmental Services, Inc., HRUBOUT Process In Situ
T0389	HyroScience, Inc., Hydrolytic Terrestrial Dissipation
T0395	Idaho Research Foundation, Inc., and White Shield, Inc., Simplot Anaerobic Biological Remediation (SABRE)
T0398	IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0399	IEG Technologies, Groundwater Circulation Wells (GZB)
T0400	IIT Research Institute, Radio Frequency Heating
T0408	In-Situ Fixation, Inc., Dual Auger System
T0409	In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0411	Institute of Gas Technology, Fluid Extraction—Biological Degradation
T0416	Intech One Eighty, White-Rot Fungus
T0419	Integrated Chemistries, Inc., Pentagone
T0430	ISOTRON Corporation, Electrokinetic Decontamination Process
T0432	IT Corporation, Below-Grade Bioremediation
T0433	IT Corporation, Biofast
T0438	IT Corporation, Enhanced Natural Degradation (END)
T0445	IT Corporation, Ozonation
T0447	IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0448	IT Corporation, Slurry-Phase Bioremediation—Pilot Scale
T0449	IT Corporation, Thermal Desorption
T0450	IT Corporation, Thermal Destruction Unit
T0452	Joule-Heated Vitrification—General
T0458	Kenox Technology Corporation, Wet Air Oxidation
T0461	Kinit Enterprises, Trozone Soil Remediation System
T0470	Lambda Bioremediation Systems, Inc., Bioremediation
T0471	Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0473	Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0480	Linatex, Inc., Soil/Sediment Washing Technology
T0490	M4 Environmental, L.P., Catalytic Extraction Process
T0492	Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493	ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494	ManTech Environmental Corporation, CleanOX Process
T0495	Maple Engineering Services, Inc., Biopur
T0498	Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0499	Maxymillian Technologies, Inc., Indirect System
T0502	McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0509	Metal-Based Permeable Reactive Barriers—General

T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0516 Metcalf & Eddy, Inc., ORG-X
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0532 Modified Natural Clays—General
T0536 Molten Salt Oxidation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0542 Mycotech Corporation, Fungal Bioremediation
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0579 On-Site Thermal Services Division of Soil Restoration and Recycling, L.L.C., Low-Temperature Thermal Desorption Plant
T0584 Osprey Biotechnics, Munox
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0601 Permeable Reactive Barriers (PRBs)—General
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0612 Plasma Environmental Technologies, Inc., Plasma Arcing Conversion (PARCON) Unit
T0617 PPC Biofilter, Biofiltration Systems
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0631 Purus, Inc., Pulsed UV Irradiation
T0632 Pyrolysis—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0642 Recol Engineering, Ltd., RYMOX Technology
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0662 RGF Environmental Group, CO3P System
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0667 RMT, Inc., Metal Treatment Technology (MTTTM)
T0670 Rohm and Haas Company, Amberlite XAD-4
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0676 Rusmar, Inc., Long-Duration Foam
T0679 S.M.W. Seiko, Inc., Soil–Cement Mixing Wall
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0696 Science Applications International Corporation, Plasma Hearth Process
T0699 SDTX Technologies, Inc., KPEG
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0705 Separation and Recovery Systems, Inc., SAREX Chemical Fixation Process
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)

T0719 Soil/Sediment Washing—General
T0721 Soil Flushing—General
T0723 Soil Technology, Inc., Remediation Technologies Using Electrolytically Produced Water
T0728 Solox, Hybrid Solar/Electric Ultraviolet Oxidation System
T0732 Solvent Extraction—General
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0753 Summit Research Corporation, Supercritical Water Oxidation
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0763 Tallon, Inc., Virtokele
T0769 Terra Resources, Ltd., Terra Wash Soil Washing
T0774 Terra Vac, Inc., Biovac
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0794 Thermal Desorption—General
T0802 ThermoRetec, Microbial Fence
T0804 ThermoRetec, Slurry-Phase Bioremediation
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0817 T-Thermal Company, Submerged Quench Incineration
T0821 U.S. EPA and IT Corporation, Debris Washing System
T0822 U.S. EPA National Risk Management Research Laboratory, Base-Catalyzed Decomposition
T0823 U.S. Filter Corporation, PO*WW*ER Wastewater Treatment System
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0852 US EPA Risk Reduction Engineering Laboratory, Mobile Volume Reduction Unit (VRU)
T0853 UV Technologies, Inc., UV-CATOX Technology
T0857 Vendor Unknown, Calochroma Soil Washing
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0869 Waste Microbes International (WMI), Inc., WMI-2000
T0888 Wet Oxidation—General
T0889 White-Rot Fungus—General
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0893 WRS Infrastructure & Environmental, Inc., Thermal Desorption Unit
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

PHENOLS

T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0101 Bio-Genesis Technologies, Aerobic Biotreatment System (ABS)
T0113 Bioremediation Service, Inc., AquaPlant Biofilter System
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0178 Constructed Wetlands—General
T0185 Corrpro Companies Incorporated, Electroremediation
T0196 Dames & Moore, Bioinfiltration
T0202 Detox Industries, Inc., DETOX Process
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0236 Electrokinetic Remediation—General
T0256 Ensite, Inc., SafeSoil
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0281 Environmental Resources Management Corporation (ERM), Advanced Fluidized Composting (AFC)
T0303 Extraksol (vendor unknown)
T0309 Fixed-Bed Soil Biofilters—General
T0320 Funderburk & Associates, Solidification Process
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0411 Institute of Gas Technology, Fluid Extraction—Biological Degradation
T0423 InterBio, Phenobac
T0445 IT Corporation, Ozonation
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0509 Metal-Based Permeable Reactive Barriers—General
T0546 Natural Attenuation—General
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0615 Polymer-Based Solidification/Stabilization—General
T0636 Quad Environmental Technologies Corporation, Chemtact Gaseous Waste Treatment
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0673 Rotating Biological Contactors—General
T0679 S.M.W. Seiko, Inc., Soil–Cement Mixing Wall
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0692 SCC Environmental, Micro-Flo

T0726 Solidification/Stabilization—General
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0755 Supercritical Carbon Dioxide Extraction—General
T0779 Terra Vac, Inc., Vacuum Extraction
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0802 ThermoRetec, Microbial Fence
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II

PLATINUM

T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0583 Oregon State University, Chitosan Beads
T0704 Selective Environmental Technologies, Inc., MAG*SEP

PLUTONIUM

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0058 Arctic Foundations, Inc., Cryogenic Barrier
T0059 Argonne National Laboratory, Advanced Integrated Solvent Extraction and Ion Exchange Systems
T0060 Argonne National Laboratory, Aqueous Biphasic Extraction System
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0064 Argonne National Laboratory, Magnetically Assisted Chemical Separation (MACS)
T0066 Argonne National Laboratory, Transuranium Extraction (TRUEX) Process
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0230 EET Corporation, Microwaste Waste Solidification
T0232 Eichrom Industries, Inc., Diphonix
T0304 F2 Associates, Inc., Laser Ablation
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0429 International Process Systems, Inc., High-Force Magnetic Separators
T0452 Joule-Heated Vitrification—General
T0485 Los Alamos National Laboratory, High-Gradient Magnetic Separation for Radioactive Soils and Process Wastes
T0486 Los Alamos National Laboratory, Uranium Heap Leaching Technology
T0536 Molten Salt Oxidation—General
T0546 Natural Attenuation—General
T0569 Oak Ridge National Laboratory, Glass Material Oxidation and Dissolution System
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System

T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0624 Proactive Applied Solutions Corporation, LEADX
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0678 S.G. Frantz Company, Inc., Magnetic Barrier Separation
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0798 Thermo Nuclean, Segmented Gate System (SGS)
T0808 Toledo Engineering Company, Inc., High-Temperature Joule-Heated Vitrification
T0819 U.S. Department of Energy Laboratories, Enhanced Sludge Washing
T0830 U.S. Naval Academy, Air Classifier with Removal of Metals from Soil
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0850 UOP, Ionsiv IE-911 Ion Exchange Resins
T0851 UOP, TIE-96 Ion Exchange Resins
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process

POLYCYCLIC AROMATIC HYDROCARBONS WITH MORE THAN FIVE FUSED RINGS

Benzo(*g*,*h*,*i*)perylene

T0001 3M Company, 3M Empore Extraction Disk
T0017 Advanced Soil Technologies, Thermal Desorption
T0048 Aqualogy BioRemedics Environmental Quality, PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0159 Charbon Consultants, HCZyme
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0225 Ecology Technologies International, Inc., FyreZyme
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0416 Intech One Eighty, White-Rot Fungus
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption

T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0889 White-Rot Fungus—General

Polycyclic Aromatic Hydrocarbons with More Than Five Fused Rings

T0001 3M Company, 3M Empore Extraction Disk
T0017 Advanced Soil Technologies, Thermal Desorption
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0159 Charbon Consultants, HCZyme
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0225 Ecology Technologies International, Inc., FyreZyme
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0416 Intech One Eighty, White-Rot Fungus
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0889 White-Rot Fungus—General

POLYCYCLIC AROMATIC HYDROCARBONS, FOUR-RING COMPOUNDS

Benzo(*a*)anthracene

T0001 3M Company, 3M Empore Extraction Disk
T0017 Advanced Soil Technologies, Thermal Desorption
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz

T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0167 Clean Technologies, Pyrodigestion
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0215 DuraTherm, Inc., DuraTherm Desorption
T0225 Ecology Technologies International, Inc., FyreZyme
T0231 EFX Systems, Inc., Granular Activated Carbon-Fluidized Bed Reactor (GAC FBR) Process
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0529 Millgard Corporation, MecTool Remediation System
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System

T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General

Chrysene

T0001 3M Company, 3M Empore Extraction Disk
T0017 Advanced Soil Technologies, Thermal Desorption
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0161 Chemical Oxidation—General
T0167 Clean Technologies, Pyrodigestion
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0195 DAHL & Associates, Inc., ThermNet
T0215 DuraTherm, Inc., DuraTherm Desorption
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized-Bed Reactor (GAC FBR) Process
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General

T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0763 Tallon, Inc., Virtokele
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General

Polycyclic Aromatic Hydrocarbons with Four Fused Rings

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0017 Advanced Soil Technologies, Thermal Desorption
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0144 Carus Chemical Company, CAIROX Potassium Permanganate

T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0167 Clean Technologies, Pyrodigestion
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0175 Composting—General
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0195 DAHL & Associates, Inc., ThermNet
T0215 DuraTherm, Inc., DuraTherm Desorption
T0225 Ecology Technologies International, Inc., FyreZyme
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized-Bed Reactor (GAC FBR) Process
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0309 Fixed-Bed Soil Biofilters—General
T0321 Fungi Perfecti, Mycova Mycoremediation and Mycofiltration
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0400 IIT Research Institute, Radio Frequency Heating
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0412 Institute of Gas Technology, MGP-REM
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0529 Millgard Corporation, MecTool Remediation System
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)

T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0719 Soil/Sediment Washing—General
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0763 Tallon, Inc., Virtokele
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General

Pyrene

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0017 Advanced Soil Technologies, Thermal Desorption
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General

T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0175 Composting—General
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0195 DAHL & Associates, Inc., ThermNet
T0215 DuraTherm, Inc., DuraTherm Desorption
T0225 Ecology Technologies International, Inc., FyreZyme
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0309 Fixed-Bed Soil Biofilters—General
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0400 IIT Research, Institute Radio Frequency Heating
T0407 In Situ Steam-Enhanced Extraction—General
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0719 Soil/Sediment Washing—General
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0763 Tallon, Inc., Virtokele

T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0889 White-Rot Fungus—General

POLYCYCLIC AROMATIC HYDROCARBONS, TWO- OR THREE-RING COMPOUNDS

Acenaphthene

T0001 3M Company, 3M Empore Extraction Disk
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0138 Calgon Carbon Corporation, Perox-Pure
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0167 Clean Technologies, Pyrodigestion
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0215 DuraTherm, Inc., DuraTherm Desorption
T0225 Ecology Technologies International, Inc., FyreZyme
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized-Bed Reactor (GAC FBR) Process
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0320 Funderburk & Associates, Solidification Process
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)

T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General
T0412 Institute of Gas Technology, MGP-REM
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0546 Natural Attenuation—General
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0755 Supercritical Carbon Dioxide Extraction—General
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In situThermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0889 White-Rot Fungus—General

Acenaphthylene

T0001 3M Company, 3M Empore Extraction Disk
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0035 American Combustion, Inc., Pyretron Thermal Destruction System
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0138 Calgon Carbon Corporation, Perox-Pure
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized-Bed Reactor (GAC FBR) Process
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)

T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General
T0416 Intech One Eighty, White-Rot Fungus
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0546 Natural Attenuation—General
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0755 Supercritical Carbon Dioxide Extraction—General
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0889 White-Rot Fungus—General

Anthracene

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0017 Advanced Soil Technologies, Thermal Desorption
T0035 American Combustion, Inc., Pyretron Thermal Destruction System
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0138 Calgon Carbon Corporation, Perox-Pure
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0161 Chemical Oxidation—General
T0167 Clean Technologies, Pyrodigestion
T0215 DuraTherm, Inc., DuraTherm Desorption
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0273 Environmental BioTechnologies, Inc., Fungal Composting

T0277 Environmental Remediation Consultants, Inc., Biointegration
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0309 Fixed-Bed Soil Biofilters—General
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0755 Supercritical Carbon Dioxide Extraction—General
T0763 Tallon, Inc., Virtokele
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0838 United Retek Corporation, Asphalt Emulsion Stabilization

T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0889 White-Rot Fungus—General

Methylnaphthalene

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0017 Advanced Soil Technologies, Thermal Desorption
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0215 DuraTherm, Inc., DuraTherm Desorption
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0348 GHEA Associates, Soil Washing Technology
T0373 Horizontal Drilling—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0613 Plasma Vitrification—General
T0659 Resources Conservation Company Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0838 United Retek Corporation, Asphalt Emulsion Stabilization

Naphthalene

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0035 American Combustion, Inc., Pyretron Thermal Destruction System

T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0084 Battelle Pacific Northwest Laboratory, Gas-Phase Corona Reactor
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0100 BioGenesis Enterprises, Inc., Soil Remediation and Cleaning Products
T0108 Biomin, Inc., Organoclay
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0126 Bioventing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0129 Bogart Environmental Services, Inc., MiKIE
T0135 Calgon Carbon Corporation, Activated Carbon
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0165 Cherokee Environmental Group, The Bio-Solution
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0167 Clean Technologies, Pyrodigestion
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0175 Composting—General
T0178 Constructed Wetlands—General
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0193 Current Environmental Solutions, L.L.C., In Situ Corona
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0205 Diversified Remediation Controls, Inc., Turbostripper
T0215 DuraTherm, Inc., DuraTherm Desorption
T0225 Ecology Technologies International, Inc., FyreZyme
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation

T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0384 Hydraulic Fracturing—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0411 Institute of Gas Technology, Fluid Extraction—Biological Degradation
T0412 Institute of Gas Technology, MGP-REM
T0414 Institute of Gas Technology, SELPhOx
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0487 Louisiana State University, Colloidal Gas Aphron
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0495 Maple Engineering Services, Inc., Biopur
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0500 Maxymillian Technologies, Inc., Thermal Desorption System
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0531 Mirage Systems, Inc., ChemChar Process
T0546 Natural Attenuation—General
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0578 OnSite Technology, L.L.C., Portable Indirect Thermal Desorption (ITD)
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0613 Plasma Vitrification—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0684 Sanexen Environmental Services, Inc., Biolysis
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0696 Science Applications International Corporation, Plasma Hearth Process
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0719 Soil/Sediment Washing—General
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0746 STC Remediation, Inc., Solidification/Stabilization Technology

T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0755 Supercritical Carbon Dioxide Extraction—General
T0759 Surfactants—General
T0763 Tallon, Inc., Virtokele
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0799 ThermoChem, Inc., PulseEnhanced Steam Reformer
T0802 ThermoRetec, Microbial Fence
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General
T0891 Williams Environmental, RamSorb-1

Phenanthrene

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0035 American Combustion, Inc., Pyretron Thermal Destruction System
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0119 Biosurfactants—General
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process

T0215 DuraTherm, Inc., DuraTherm Desorption
T0225 Ecology Technologies International, Inc., FyreZyme
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0320 Funderburk & Associates, Solidification Process
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General
T0411 Institute of Gas Technology, Fluid Extraction—Biological Degradation
T0412 Institute of Gas Technology, MGP-REM
T0414 Institute of Gas Technology, SELPhOx
T0416 Intech One Eighty, White-Rot Fungus
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0607 Phytoremediation—General
T0623 Princeton University, Magnetic Extraction of Nonionic Organic Pollutants
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0755 Supercritical Carbon Dioxide Extraction—General
T0759 Surfactants—General
T0763 Tallon, Inc., Virtokele
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction

T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0805 ThermoRetec, Thermatek Thermal Desorption
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0889 White-Rot Fungus—General

Polycyclic Aromatic Hydrocarbons With Two or Three Fused Rings

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0017 Advanced Soil Technologies, Thermal Desorption
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0035 American Combustion, Inc., Pyretron Thermal Destruction System
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0084 Battelle Pacific Northwest Laboratory, Gas-Phase Corona Reactor
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0100 BioGenesis Enterprises, Inc., Soil Remediation and Cleaning Products
T0108 Biomin, Inc., Organoclay
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0119 Biosurfactants—General
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0129 Bogart Environmental Services, Inc., MiKIE
T0135 Calgon Carbon Corporation, Activated Carbon
T0138 Calgon Carbon Corporation, Perox-Pure
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0165 Cherokee Environmental Group, The Bio-Solution
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0167 Clean Technologies, Pyrodigestion
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0175 Composting—General
T0178 Constructed Wetlands—General
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0193 Current Environmental Solutions, L.L.C., In Situ Corona
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process

T0205 Diversified Remediation Controls, Inc., Turbostripper
T0215 DuraTherm, Inc., DuraTherm Desorption
T0225 Ecology Technologies International, Inc., FyreZyme
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized-Bed Reactor (GAC FBR) Process
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0309 Fixed-Bed Soil Biofilters—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0384 Hydraulic Fracturing—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0411 Institute of Gas Technology, Fluid Extraction—Biological Degradation
T0412 Institute of Gas Technology, MGP-REM
T0414 Institute of Gas Technology, SELPhOx
T0416 Intech One Eighty, White-Rot Fungus
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0487 Louisiana State University, Colloidal Gas Aphron
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0495 Maple Engineering Services, Inc., Biopur
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0500 Maxymillian Technologies, Inc., Thermal Desorption System
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products

T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0531 Mirage Systems, Inc., ChemChar Process
T0546 Natural Attenuation—General
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0578 OnSite Technology, L.L.C., Portable Indirect Thermal Desorption (ITD)
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0602 Pet-Con Soil Remediation, Inc., Thermal Desorption
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0613 Plasma Vitrification—General
T0623 Princeton University, Magnetic Extraction of Nonionic Organic Pollutants
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0684 Sanexen Environmental Services, Inc., Biolysis
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0696 Science Applications International Corporation, Plasma Hearth Process
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0719 Soil/Sediment Washing—General
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0755 Supercritical Carbon Dioxide Extraction—General
T0759 Surfactants—General
T0763 Tallon, Inc., Virtokele
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

T0799 ThermoChem, Inc., PulseEnhanced Steam Reformer
T0802 ThermoRetec, Microbial Fence
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White Rot Fungus—General
T0891 Williams Environmental, RamSorb-1

POLYCYCLIC AROMATIC HYDROCARBONS; PAH; PNA; POM

T0001 3M Company, 3M Empore Extraction Disk
T0002 7-7, Inc., Liquefication Process
T0009 Advanced Environmental Services, Inc., System 64MT Low-Temperature Thermal Desorption
T0011 Advanced Microbial Solutions, SuperBio
T0017 Advanced Soil Technologies, Thermal Desorption
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0034 American Biotherm, L.L.C., Biotherm Process
T0035 American Combustion, Inc., Pyretron Thermal Destruction System
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0055 Arctech, Inc., Bioremediation—Solid Phase
T0057 Arctech, Inc., Ozo-Detox
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0067 Ariel Industries, Inc., Ariel SST Low-Temperature Thermal Desorber
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0078 Barr Engineering Company, Co-Burning Technology
T0093 Bio Solutions, Inc., Soil Slurry-Sequencing Batch Reactor
T0095 Bio-Electrics, Inc., Electrofrac Detoxification System
T0098 BioGee International, Inc., BioGee HC
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0100 BioGenesis Enterprises, Inc., Soil Remediation and Cleaning Products
T0101 Bio-Genesis Technologies, Aerobic Biotreatment System (ABS)
T0105 Biogenie, Inc., Biogenie Biopile
T0108 Biomin, Inc., Organoclay
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment

T0129 Bogart Environmental Services, Inc., MiKIE
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0141 Carbon Dioxide Pellet Surface Cleaning—General
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0143 Carson Environmental, Low-Temperature Oxidation
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0158 CH2M Hill, Phytoremediation-Based Systems
T0159 Charbon Consultants, HCZyme
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0161 Chemical Oxidation—General
T0164 ChemPete, Inc., Bioremediation
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0178 Constructed Wetlands—General
T0182 ConTeck Environmental Services, Inc., Soil Roaster
T0189 CryoGenesis, Cryogenesis Surface Decontamination System
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0193 Current Environmental Solutions, L.L.C., In Situ Corona
T0195 DAHL & Associates, Inc., ThermNet
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0202 Detox Industries, Inc., DETOX Process
T0204 Distillation—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0223 Earth Tech Bioremediation—Solid Phase
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized-Bed Reactor (GAC FBR) Process
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0256 Ensite, Inc., SafeSoil
T0266 Envirogen, Inc., Solid Organic Phase Extraction (SoPE)
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE
T0272 Environment Canada, Microwave-Assisted Process
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)

T0292 EnviroWall, Inc., EnviroWall Barrier
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0298 Eriksson Sediment Systems, Inc., Eriksson System
T0300 ETUS, Inc., Enhanced Bioremediation
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0303 Extraksol (vendor unknown)
T0309 Fixed-Bed Soil Biofilters—General
T0317 freezeWALL, Inc., freezeWALL Process
T0318 FRX, Inc., Hydraulic Fracturing
T0321 Fungi Perfecti, Mycova Mycoremediation and Mycofiltration
T0329 General Atomics, Supercritical Water Oxidation
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0348 GHEA Associates, Soil Washing Technology
T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0364 Harding ESE, Inc., Bioremediation—Landfarming Treatment
T0365 Harding ESE, Inc., Composting
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0373 Horizontal Drilling—General
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process In Situ
T0384 Hydraulic Fracturing—General
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0386 Hydrocarbon Environmental Recovery Systems, Bioremediation Response Advancement Technologies (BRAT)
T0388 Hydrogen Peroxide In Situ Bioremediation—General
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0399 IEG Technologies, Groundwater Circulation Wells (GZB)
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0411 Institute of Gas Technology, Fluid Extraction—Biological Degradation
T0412 Institute of Gas Technology, MGP-REM
T0414 Institute of Gas Technology, SELPhOx
T0416 Intech One Eighty, White-Rot Fungus
T0419 Integrated Chemistries, Inc., Pentagone
T0433 IT Corporation, Biofast
T0437 IT Corporation, Engineered Bioremediation System
T0438 IT Corporation, Enhanced Natural Degradation (END)
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0448 IT Corporation, Slurry-Phase Bioremediation—Pilot Scale
T0449 IT Corporation, Thermal Desorption
T0450 IT Corporation, Thermal Destruction Unit
T0454 KAL CON Environmental Services, Thermal Desorption
T0457 KEMRON Environmental Services, Inc., Bioremediation—Soil and Groundwater

T0458 Kenox Technology Corporation, Wet Air Oxidation
T0461 Kinit Enterprises, Trozone Soil Remediation System
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0468 KVA, C-Sparger System
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0487 Louisiana State University, Colloidal Gas Aphron
T0489 M.L. Chartier, Inc., Therminator
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0495 Maple Engineering Services, Inc., Biopur
T0496 MARCOR Remediation, Inc., Advanced Chemical Treatment
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0500 Maxymillian Technologies, Inc., Thermal Desorption System
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0516 Metcalf & Eddy, Inc., ORG-X
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0541 MYCELX Technologies Corporation, MYCELX
T0542 Mycotech Corporation, Fungal Bioremediation
T0546 Natural Attenuation—General
T0553 New Jersey Institute of Technology, Ultrasound-Enhanced Soil Washing
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0599 PerkinElmer, Inc., NoVOCs
T0602 Pet-Con Soil Remediation, Inc., Thermal Desorption
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0612 Plasma Environmental Technologies, Inc., Plasma Arcing Conversion (PARCON) Unit
T0623 Princeton University, Magnetic Extraction of Nonionic Organic Pollutants
T0628 PTC Enterprises, BioTreat System
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0632 Pyrolysis—General
T0633 Pyrovac International, Inc., Pyrocycling Process
T0638 R.E. Wright Environmental, Inc., Steam Enhanced Recovery
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)

T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0676 Rusmar, Inc., Long-Duration Foam
T0679 S.M.W. Seiko, Inc., Soil–Cement Mixing Wall
T0684 Sanexen Environmental Services, Inc., Biolysis
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0696 Science Applications International Corporation, Plasma Hearth Process
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0705 Separation and Recovery Systems, Inc., SAREX Chemical Fixation Process
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0719 Soil/Sediment Washing—General
T0723 Soil Technology, Inc., Remediation Technologies Using Electrolytically Produced Water
T0735 Sound Remedial Technologies, Inc., Hot Air Vapor Extraction (HAVE)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0753 Summit Research Corporation, Supercritical Water Oxidation
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0759 Surfactants—General
T0760 Surtek, Inc., Surfactant Remediation
T0761 Sybron Chemicals, Inc., ABR (Augmented Bioreclamation) Microbial Blends
T0762 Syracuse University, Supercritical Fluid Extraction
T0763 Tallon, Inc., Virtokele
T0764 Tarmac Environmental Company, Inc., Thermal Desorption
T0768 Tekno Associates, Biolift
T0779 Terra Vac, Inc., Vacuum Extraction
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0794 Thermal Desorption—General

T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0802 ThermoRetec, Microbial Fence
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0809 Toronto Harbour Commissioners, Soil Recycle Treatment Train
T0811 TPS Technologies, Inc., Thermal Desorption
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0818 TVIES, Inc., Soil Washing
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0852 US EPA Risk Reduction Engineering Laboratory, Mobile Volume Reduction Unit (VRU)
T0853 UV Technologies, Inc., UV-CATOX Technology
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0869 Waste Microbes International (WMI), Inc., WMI-2000
T0870 Waste Stream Technology, Inc., Bioremediation
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0888 Wet Oxidation—General
T0889 White-Rot Fungus—General
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0893 WRS Infrastructure & Environmental, Inc., Thermal Desorption Unit
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat

POLYCYCLIC HYDROCARBONS, NONALTERNANT COMPOUNDS WITH FOUR FUSED RINGS

Fluoranthene

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0017 Advanced Soil Technologies, Thermal Desorption
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0035 American Combustion, Inc., Pyretron Thermal Destruction System
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0167 Clean Technologies, Pyrodigestion
T0171 CMI Corporation, Enviro-Tech Thermal Desorption

T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0195 DAHL & Associates, Inc., ThermNet
T0225 Ecology Technologies International, Inc., FyreZyme
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0755 Supercritical Carbon Dioxide Extraction—General
T0763 Tallon, Inc., Virtokele
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0889 White-Rot Fungus—General

Four-Ring Fused Nonalternant Hydrocarbons

T0001 3M Company, 3M Empore Extraction Disk
T0011 Advanced Microbial Solutions, SuperBio
T0017 Advanced Soil Technologies, Thermal Desorption
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0035 American Combustion, Inc., Pyretron Thermal Destruction System
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0167 Clean Technologies, Pyrodigestion
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0195 DAHL & Associates, Inc., ThermNet
T0225 Ecology Technologies International, Inc., FyreZyme
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation

T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0755 Supercritical Carbon Dioxide Extraction—General
T0763 Tallon, Inc., Virtokele
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0889 White-Rot Fungus—General

POLYCYCLIC HYDROCARBONS, NONALTERNANT COMPOUNDS WITH FIVE FUSED RINGS

Benzo(*b*)fluoranthene

T0001 3M Company, 3M Empore Extraction Disk
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0195 DAHL & Associates, Inc., ThermNet
T0225 Ecology Technologies International, Inc., FyreZyme
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption

T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0529 Millgard Corporation, MecTool Remediation System
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General

Benzo(*k*)fluoranthene

T0001 3M Company, 3M Empore Extraction Disk
T0017 Advanced Soil Technologies, Thermal Desorption
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0225 Ecology Technologies International, Inc., FyreZyme
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)

T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0529 Millgard Corporation, MecTool Remediation System
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0755 Supercritical Carbon Dioxide Extraction—General
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General

Polycyclic Hydrocarbons, Nonalternant Compounds with Five Fused Rings

T0001 3M Company, 3M Empore Extraction Disk
T0017 Advanced Soil Technologies, Thermal Desorption
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0195 DAHL & Associates, Inc., ThermNet
T0225 Ecology Technologies International, Inc., FyreZyme
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation

T0407 In Situ Steam-Enhanced Extraction—General
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0529 Millgard Corporation, MecTool Remediation System
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0755 Supercritical Carbon Dioxide Extraction—General
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General

POLYCYCLIC HYDROCARBONS, NONALTERNANT COMPOUNDS WITH FUSED RINGS

T0001 3M Company, 3M Empore Extraction Disk
T0002 7-7, Inc., Liquefication Process
T0009 Advanced Environmental Services, Inc., System 64MT Low-Temperature Thermal Desorption
T0011 Advanced Microbial Solutions, SuperBio
T0017 Advanced Soil Technologies, Thermal Desorption
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0034 American Biotherm, L.L.C., Biotherm Process
T0035 American Combustion, Inc., Pyretron Thermal Destruction System
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0055 Arctech, Inc., Bioremediation—Solid Phase
T0057 Arctech, Inc., Ozo-Detox

T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0067 Ariel Industries, Inc., Ariel SST Low-Temperature Thermal Desorber
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0078 Barr Engineering Company, Co-Burning Technology
T0093 Bio Solutions, Inc., Soil Slurry-Sequencing Batch Reactor
T0095 Bio-Electrics, Inc., Electrofrac Detoxification System
T0098 BioGee International, Inc., BioGee HC
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0100 BioGenesis Enterprises, Inc., Soil Remediation and Cleaning Products
T0101 Bio-Genesis Technologies, Aerobic Biotreatment System (ABS)
T0105 Biogenie, Inc., Biogenie Biopile
T0108 Biomin, Inc., Organoclay
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0129 Bogart Environmental Services, Inc., MiKIE
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0141 Carbon Dioxide Pellet Surface Cleaning—General
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0143 Carson Environmental, Low-Temperature Oxidation
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0158 CH2M Hill, Phytoremediation-Based Systems
T0159 Charbon Consultants, HCZyme
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0161 Chemical Oxidation—General
T0164 ChemPete, Inc., Bioremediation
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0178 Constructed Wetlands—General
T0182 ConTeck Environmental Services, Inc., Soil Roaster
T0189 CryoGenesis, Cryogenesis Surface Decontamination System
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0193 Current Environmental Solutions, L.L.C., In Situ Corona
T0195 DAHL & Associates, Inc., ThermNet
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0202 Detox Industries, Inc., DETOX Process

T0204 Distillation—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0223 Earth Tech, Bioremediation—Solid Phase
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized-Bed Reactor (GAC FBR) Process
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0256 Ensite, Inc., SafeSoil
T0266 Envirogen, Inc., Solid Organic Phase Extraction (SoPE)
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE
T0272 Environment Canada, Microwave-Assisted Process
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0292 EnviroWall, Inc., EnviroWall Barrier
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0298 Eriksson Sediment Systems, Inc., Eriksson System
T0300 ETUS, Inc., Enhanced Bioremediation
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0303 Extraksol (vendor unknown)
T0309 Fixed-Bed Soil Biofilters—General
T0317 freezeWALL, Inc., freezeWALL Process
T0318 FRX, Inc., Hydraulic Fracturing
T0321 Fungi Perfecti, Mycova Mycoremediation and Mycofiltration
T0329 General Atomics, Supercritical Water Oxidation
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0348 GHEA Associates, Soil Washing Technology
T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0364 Harding ESE, Inc., Bioremediation—Landfarming Treatment
T0365 Harding ESE, Inc., Composting
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0373 Horizontal Drilling—General
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process In Situ
T0384 Hydraulic Fracturing—General
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0386 Hydrocarbon Environmental Recovery Systems, Bioremediation Response Advancement Technologies (BRAT)
T0388 Hydrogen Peroxide In Situ Bioremediation—General

T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0399 IEG Technologies, Groundwater Circulation Wells (GZB)
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0411 Institute of Gas Technology, Fluid Extraction—Biological Degradation
T0412 Institute of Gas Technology, MGP-REM
T0414 Institute of Gas Technology, SELPhOx
T0416 Intech One Eighty, White-Rot Fungus
T0419 Integrated Chemistries, Inc., Pentagone
T0433 IT Corporation, Biofast
T0437 IT Corporation, Engineered Bioremediation System
T0438 IT Corporation, Enhanced Natural Degradation (END)
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0448 IT Corporation, Slurry-Phase Bioremediation—Pilot Scale
T0449 IT Corporation, Thermal Desorption
T0450 IT Corporation, Thermal Destruction Unit
T0454 KAL CON Environmental Services, Thermal Desorption
T0457 KEMRON Environmental Services, Inc., Bioremediation—Soil and Groundwater
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0461 Kinit Enterprises, Trozone Soil Remediation System
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0468 KVA, C-Sparger System
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0487 Louisiana State University, Colloidal Gas Aphron
T0489 M.L. Chartier, Inc., Therminator
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0495 Maple Engineering Services, Inc., Biopur
T0496 MARCOR Remediation, Inc., Advanced Chemical Treatment
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0500 Maxymillian Technologies, Inc., Thermal Desorption System
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0516 Metcalf & Eddy, Inc., ORG-X
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0541 MYCELX Technologies Corporation, MYCELX
T0542 Mycotech Corporation, Fungal Bioremediation
T0546 Natural Attenuation—General

T0553 New Jersey Institute of Technology, Ultrasound-Enhanced Soil Washing
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0599 PerkinElmer, Inc., NoVOCs
T0602 Pet-Con Soil Remediation, Inc., Thermal Desorption
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0612 Plasma Environmental Technologies, Inc., Plasma Arcing Conversion (PARCON) Unit
T0623 Princeton University, Magnetic Extraction of Nonionic Organic Pollutants
T0628 PTC Enterprises, BioTreat System
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0632 Pyrolysis—General
T0633 Pyrovac International, Inc., Pyrocycling Process
T0638 R.E. Wright Environmental, Inc., Steam-Enhanced Recovery
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0676 Rusmar, Inc., Long-Duration Foam
T0679 S.M.W. Seiko, Inc., Soil–Cement Mixing Wall
T0684 Sanexen Environmental Services, Inc., Biolysis
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0696 Science Applications International Corporation, Plasma Hearth Process
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0705 Separation and Recovery Systems, Inc., SAREX Chemical Fixation Process
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0719 Soil/Sediment Washing—General
T0723 Soil Technology, Inc., Remediation Technologies Using Electrolytically Produced Water
T0735 Sound Remedial Technologies, Inc., Hot Air Vapor Extraction (HAVE)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology

T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0753 Summit Research Corporation, Supercritical Water Oxidation
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0759 Surfactants—General
T0760 Surtek, Inc., Surfactant Remediation
T0761 Sybron Chemicals, Inc., ABR (Augmented Bioreclamation) Microbial Blends
T0762 Syracuse University, Supercritical Fluid Extraction
T0763 Tallon, Inc., Virtokele
T0764 Tarmac Environmental Company, Inc., Thermal Desorption
T0768 Tekno Associates, Biolift
T0779 Terra Vac, Inc., Vacuum Extraction
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0794 Thermal Desorption—General
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0802 ThermoRetec, Microbial Fence
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0809 Toronto Harbour Commissioners, Soil Recycle Treatment Train
T0811 TPS Technologies, Inc., Thermal Desorption
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0818 TVIES, Inc., Soil Washing
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0852 US EPA Risk Reduction Engineering Laboratory, Mobile Volume Reduction Unit (VRU)
T0853 UV Technologies, Inc., UV-CATOX Technology
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0869 Waste Microbes International (WMI), Inc., WMI-2000
T0870 Waste Stream Technology, Inc., Bioremediation
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0888 Wet Oxidation—General
T0889 White-Rot Fungus—General
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0893 WRS Infrastructure & Environmental, Inc., Thermal Desorption Unit
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat

POLYCYCLIC HYDROCARBONS, NONALTERNANT COMPOUNDS WITH MORE THAN FIVE FUSED RINGS

Indeno(1,2,3-*cd*)pyrene

T0001 3M Company, 3M Empore Extraction Disk
T0017 Advanced Soil Technologies, Thermal Desorption
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0416 Intech One Eighty, White-Rot Fungus
T0447 IT Corporation, Slurry Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General

Polycyclic Hydrocarbons, Nonalternant Compounds with More Than Five Fused Rings

T0001 3M Company, 3M Empore Extraction Disk
T0017 Advanced Soil Technologies, Thermal Desorption
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process

T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0416 Intech One Eighty, White-Rot Fungus
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General

POLYCYCLIC HYDROCARBONS, NONALTERNANT COMPOUNDS WITH TWO OR THREE FUSED RINGS

Fluorene

T0011 Advanced Microbial Solutions, SuperBio
T0017 Advanced Soil Technologies, Thermal Desorption
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0035 American Combustion, Inc., Pyretron Thermal Destruction System
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0161 Chemical Oxidation—General
T0167 Clean Technologies, Pyrodigestion

T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0215 DuraTherm, Inc., DuraTherm Desorption
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General
T0412 Institute of Gas Technology, MGP-REM
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0719 Soil/Sediment Washing—General
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0889 White-Rot Fungus—General

Indene

T0320 Funderburk & Associates, Solidification Process

Polycyclic Hydrocarbons, Nonalternant Compounds with Two or Three Fused Rings

T0011 Advanced Microbial Solutions, SuperBio
T0017 Advanced Soil Technologies, Thermal Desorption
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0035 American Combustion, Inc., Pyretron Thermal Destruction System
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0161 Chemical Oxidation—General
T0167 Clean Technologies, Pyrodigestion
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0215 DuraTherm, Inc., DuraTherm Desorption
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0320 Funderburk & Associates, Solidification Process
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General
T0412 Institute of Gas Technology, MGP-REM
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0719 Soil/Sediment Washing—General
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)

T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0840 United States Department of Agriculture Forest Service—Forest Products Laboratory, *Phanerochaete sordida*
T0889 White-Rot Fungus—General

POLYCYCLIC AROMATIC HYDROCARBONS, FIVE-RING COMPOUNDS

Benzo(*a*)pyrene

T0001 3M Company, 3M Empore Extraction Disk
T0017 Advanced Soil Technologies, Thermal Desorption
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0167 Clean Technologies, Pyrodigestion
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0195 DAHL & Associates, Inc., ThermNet
T0215 DuraTherm, Inc., DuraTherm Desorption
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General
T0411 Institute of Gas Technology, Fluid Extraction—Biological Degradation

T0414 Institute of Gas Technology, SELPhOx
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0529 Millgard Corporation, MecTool Remediation System
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0618 Praxair, Inc., MixFlo
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0755 Supercritical Carbon Dioxide Extraction—General
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General

Dibenzo(*a*, *h*)anthracene

T0001 3M Company, 3M Empore Extraction Disk
T0017 Advanced Soil Technologies, Thermal Desorption
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0159 Charbon Consultants, HCZyme
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0225 Ecology Technologies International, Inc., FyreZyme
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)

T0309 Fixed-Bed Soil Biofilters—General
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0838 United Retek Corporation, Asphalt Emulsion Stabilization

Polycyclic Aromatic Hydrocarbons with Five Fused Rings

T0001 3M Company, 3M Empore Extraction Disk
T0017 Advanced Soil Technologies, Thermal Desorption
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0167 Clean Technologies, Pyrodigestion
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0175 Composting—General
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0195 DAHL & Associates, Inc., ThermNet
T0215 DuraTherm, Inc., DuraTherm Desorption
T0225 Ecology Technologies International, Inc., FyreZyme
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0273 Environmental BioTechnologies, Inc., Fungal Composting
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption

T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0309 Fixed-Bed Soil Biofilters—General
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0407 In Situ Steam-Enhanced Extraction—General
T0411 Institute of Gas Technology Fluid Extraction—Biological Degradation
T0412 Institute of Gas Technology, MGP-REM
T0414 Institute of Gas Technology, SELPhOx
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0529 Millgard Corporation, MecTool Remediation System
T0598 Pelorus EnBiotech Corporation, Slurry-Phase Bioremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0618 Praxair, Inc., MixFlo
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0755 Supercritical Carbon Dioxide Extraction—General
T0763 Tallon, Inc., Virtokele
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0889 White-Rot Fungus—General

POTASSIUM

T0005 Active Environmental Technologies, Inc., TechXtract
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0178 Constructed Wetlands—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0236 Electrokinetic Remediation—General
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric

PRIMARY ALCOHOLS

Benzyl Alcohol

T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)

Butanol, *n*

T0135 Calgon Carbon Corporation, Activated Carbon
T0138 Calgon Carbon Corporation, Perox-Pure
T0212 Dual-Phase Extraction—General
T0309 Fixed-Bed Soil Biofilters—General
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0329 General Atomics, Supercritical Water Oxidation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0407 In Situ Steam-Enhanced Extraction—General
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0756 Supercritical Water Oxidation—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0794 Thermal Desorption—General
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0877 Weatherly, Inc., AQUA CRITOX
T0891 Williams Environmental, RamSorb-1

Ethanol

T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0212 Dual-Phase Extraction—General
T0329 General Atomics, Supercritical Water Oxidation
T0355 Granular Activated Carbon (GAC)—General
T0372 Hi-Point Industries, Ltd., Oclansorb
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0617 PPC Biofilter, Biofiltration systems
T0672 Rohm and Haas Company, Ambersorb 600
T0756 Supercritical Water Oxidation—General

T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0835 Umpqua Research Company, Low-Temperature Aqueous-Phase Catalytic Oxidation
T0855 Vapor-Phase Biofiltration—General
T0891 Williams Environmental, RamSorb-1

Methanol

T0033 Ambient Engineering, Inc., BIOTON
T0127 Blast Fracturing—General
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0161 Chemical Oxidation—General
T0212 Dual-Phase Extraction—General
T0281 Environmental Resources Management Corporation (ERM), Advanced Fluidized Composting (AFC)
T0329 General Atomics, Supercritical Water Oxidation
T0352 Golder Associates Corporation, Montan Wax Barrier
T0355 Granular Activated Carbon (GAC)—General
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0617 PPC Biofilter, Biofiltration Systems
T0672 Rohm and Haas Company, Ambersorb 600
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0756 Supercritical Water Oxidation—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0835 Umpqua Research Company, Low-Temperature Aqueous-Phase Catalytic Oxidation
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0891 Williams Environmental, RamSorb-1

Primary Alcohols

T0033 Ambient Engineering, Inc., BIOTON
T0127 Blast Fracturing—General
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0212 Dual-Phase Extraction—General

T0281 Environmental Resources Management Corporation (ERM), Advanced Fluidized Composting (AFC)
T0309 Fixed-Bed Soil Biofilters—General
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0329 General Atomics, Supercritical Water Oxidation
T0352 Golder Associates Corporation, Montan Wax Barrier
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0407 In Situ Steam-Enhanced Extraction—General
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0617 PPC Biofilter, Biofiltration Systems
T0672 Rohm and Haas Company, Ambersorb 600
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0756 Supercritical Water Oxidation—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0835 Umpqua Research Company, Low-Temperature Aqueous-Phase Catalytic Oxidation
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0877 Weatherly, Inc., AQUA CRITOX
T0891 Williams Environmental, RamSorb-1

PRIMARY ALIPHATIC AMINES AND DIAMINES

Hexylamine

T0531 Mirage Systems, Inc., ChemChar Process

Monomethylamine

T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

Primary Aliphatic Amines

T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0531 Mirage Systems, Inc., ChemChar Process
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

PYRIDINE AND SUBSTITUTED PYRIDINES

Paraquat

T0001 3M Company, 3M Empore Extraction Disk
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats

Pentachloropyridine

T0200 Delphi Research, Inc., DETOX

Pyridine

T0005 Active Environmental Technologies, Inc., TechXtract
T0168 CleanSoil, Inc., CleanSoil Process
T0344 Geosafe Corporation, In Situ Vitrification
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0756 Supercritical Water Oxidation—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0877 Weatherly, Inc., AQUA CRITOX

Pyridine and Substituted Pyridines

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0200 Delphi Research, Inc., DETOX
T0344 Geosafe Corporation, In Situ Vitrification
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0756 Supercritical Water Oxidation—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0877 Weatherly, Inc., AQUA CRITOX

PYRROLE AND FUSED-RING DERIVATIVES OF PYRROLE

Captan

T0138 Calgon Carbon Corporation, Perox-Pure
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0755 Supercritical Carbon Dioxide Extraction—General

Pyrrole and Fused-Ring Derivatives of Pyrrole

T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0138 Calgon Carbon Corporation, Perox-Pure
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0755 Supercritical Carbon Dioxide Extraction—General
T0855 Vapor-Phase Biofiltration—General

RADIONUCLIDES

T0001 3M Company, 3M Empore Extraction Disk
T0004 Activated Alumina—General
T0005 Active Environmental Technologies, Inc., TechXtract
T0007 ADTECHS Corporation, Radionuclide Separation Process (RASEP)
T0008 ADTECHS Corporation, Wet Oxidation (WetOx) Process
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0013 Advanced Recovery Systems, Inc., Deact Soil Washing
T0014 Advanced Recovery Systems, Inc., DeCaF
T0015 Advanced Recovery Systems, Inc., DeHg
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0023 Affinity Water Technologies, Advanced Affinity Chromatography
T0028 Alternative Biowaste Elimination Technologies (ABET), Ltd., WR2
T0030 Alternative Technologies for Waste, Inc., TerraSure
T0053 ARCADIS Geraghty and Miller, Inc., STRATEX (Stratified Temperature Extractor)
T0054 Arctech, Inc., Humasorb
T0058 Arctic Foundations, Inc., Cryogenic Barrier
T0059 Argonne National Laboratory, Advanced Integrated Solvent Extraction and Ion Exchange Systems
T0060 Argonne National Laboratory, Aqueous Biphasic Extraction System
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0064 Argonne National Laboratory, Magnetically Assisted Chemical Separation (MACS)
T0066 Argonne National Laboratory, Transuranium Extraction (TRUEX) Process
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0074 ATW, Inc., RAD-CAST
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0077 B & W Services, Inc., EcoSafe Soil Washing
T0083 Battelle Pacific Northwest Laboratory, Compact Processing Unit (CPU)
T0085 Battelle Pacific Northwest Laboratory, Subsurface Lithoautotrophic Microbial Ecosystem (SLiME)
T0088 Battelle Pacific Northwest National Laboratory, Terra-VIT Vitrification Technology
T0118 Biosorption—General
T0127 Blast Fracturing—General
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0134 CAE Alpheus, Inc., Carbon Dioxide Blasting
T0139 Cancrete Environmental Solutions, Inc., Depocrete
T0141 Carbon Dioxide Pellet Surface Cleaning—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0158 CH2M Hill, Phytoremediation-Based Systems
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology

T0163 Chem-Nuclear Systems, Inc., Thermex
T0169 Clemson University, Sintered Ceramic Stabilization
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0174 Commodore Separation Technologies, Inc., Supported Liquid Membrane
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0184 Corpex Technologies, Inc., Corpex Technology
T0189 CryoGenesis, Cryogenesis Surface Decontamination System
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0200 Delphi Research, Inc., DETOX
T0209 Dow Chemical Company, DOWEX Ion Exchange Resins
T0214 DuPont/Oberlin, Microfiltration Technology
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0230 EET Corporation, Microwaste Waste Solidification
T0232 Eichrom Industries, Inc., Diphonix
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0247 Emerging Energy Marketing Firm, Inc., Low-Energy Transmutation
T0262 Envirocare of Utah, Inc., Polyethylene Encapsulation
T0285 Environmental Technology (U.S.), Inc., TR-Detox
T0298 Eriksson Sediment Systems, Inc., Eriksson System
T0304 F2 Associates, Inc., Laser Ablation
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0315 Foster-Miller, Robotics
T0316 Freeze Crystallization—General
T0328 General Atomics, Cryofracture
T0335 Geo-Con, Inc., Deep Soil Mixing
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0343 Georgia Institute of Technology, Construction Research Center In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0352 Golder Associates Corporation, Montan Wax Barrier
T0359 GTS Duratek, DuraMelter
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0392 Idaho National Engineering Laboratory, Biological Destruction of Tank Wastes (BDTW)
T0393 Idaho National Engineering Laboratory, In Situ Grouting and Retrieval
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0404 In Situ Grouting—General
T0428 International Landmark Environmental, Inc., Diatomite
T0429 International Process Systems, Inc., High-Force Magnetic Separators
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0443 IT Corporation, In Situ Geochemical Fixation
T0452 Joule-Heated Vitrification—General
T0453 Kaiser-Hill Company, L.L.C., Supercritical Carbon Dioxide Extraction
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0466 Krudico, Inc., Ion Exchange Resins for Nitrate and Perchlorate
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water

T0474 Lawrence Livermore National Laboratory, Hot-Recycled-Solid (HRS) Retorting Process
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0481 Lockheed Martin Corporation, Acid Extraction
T0482 Lockheed Martin Corporation, TRUclean Soil Washing System
T0485 Los Alamos National Laboratory, High-Gradient Magnetic Separation for Radioactive Soils and Process Wastes
T0486 Los Alamos National Laboratory, Uranium Heap Leaching Technology
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0505 MeltTran, Inc., Ultimate Solution
T0509 Metal-Based Permeable Reactive Barriers—General
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0529 Millgard Corporation, MecTool Remediation System
T0531 Mirage Systems, Inc., ChemChar Process
T0534 Molten Metal Technology, Enviroglass
T0535 Molten Metal Technology, Inc., Quantum Catalytic Extraction Process (Q-CEP)
T0536 Molten Salt Oxidation—General
T0537 Monsanto Company, Lasagna
T0538 Montana Tech of the University of Montana, Campbell Centrifugal Jig
T0540 MSE Technology Applications, Inc., Viscous Barrier Technology
T0543 Naiad Technologies, Inc., RadAway
T0546 Natural Attenuation—General
T0569 Oak Ridge National Laboratory, Glass Material Oxidation and Dissolution System
T0570 Oak Ridge National Laboratory, SRTALK Process for Technetium Extraction
T0575 Oceaneering International, Inc., ROVCO2
T0582 Onyx Industrial Services, SOIL*EX
T0583 Oregon State University, Chitosan Beads
T0586 Pacific Northwest National Laboratory, In Situ Redox Manipulation
T0587 Pacific Northwest National Laboratory, Permeable Clinoptilolite Barriers for Strontium
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0590 PaR Systems, Inc., Dry Size Reduction System (DSRS)
T0594 PEAT, Inc., Thermal Destruction and Recovery
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0608 Phytoremediation: Hyperaccumulation—General
T0613 Plasma Vitrification—General
T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System
T0615 Polymer-Based Solidification/Stabilization—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0632 Pyrolysis—General
T0646 RedZone Robotics, Inc., Houdini
T0647 RedZone Robotics, Inc., Rosie II
T0657 Resonant Shock Compaction, L.L.C., Resonant Shock Compaction
T0658 Resource Management and Recovery, AlgaSORB
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0665 RKK-SoilFreeze Technologies, L.L.C., CRYOSWEEP
T0666 RKK-SoilFreeze Technologies, L.L.C., ISOCELL
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0677 Rust Federal Services, Inc., VAC*TRAX Thermal Desorption

T0678 S.G. Frantz Company, Inc., Magnetic Barrier Separation
T0682 Sandia National Laboratories, Electrokinetic Remediation
T0696 Science Applications International Corporation, Plasma Hearth Process
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0719 Soil/Sediment Washing—General
T0725 Solidification and Immobilization of Radioactive Wastes in Cement—General
T0726 Solidification/Stabilization—General
T0734 Sonsub International, Inc., Cryogenic Retrieval
T0737 Spar Aerospace, Ltd., Light-Duty Utility Arm
T0738 SpinTek Systems, SpinTek
T0742 Starmet Corporation, RocTec Stabilization
T0743 Starmet Corporation, DUCRETE Concrete
T0744 Startech Environmental Corporation, Plasma Waste Converter
T0752 Stir-Melter, Inc., Stir-Melter
T0753 Summit Research Corporation, Supercritical Water Oxidation
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0758 Surface Remediation Specialists, Centrifugal Shot Blast Technology
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0767 TechTran Environmental, Inc., RHM-1000 Process
T0769 Terra Resources, Ltd., Terra Wash Soil Washing
T0772 Terra Vac, Geochemical Fixation
T0786 Teton Technologies, Inc., In Situ Waste Destruction and Vitrification
T0790 Textron, Inc., Electro-Hydraulic Scabbling (EHS)
T0793 Thermal Conversion Corporation, Plasma Energy Recycle and Conversion (PERC)
T0798 Thermo Nuclean, Segmented Gate System (SGS)
T0800 ThermoEnergy Corporation, NitRem
T0801 Thermoplastic Stabilization/Solidification—General
T0808 Toledo Engineering Co., Inc., High-Temperature Joule-Heated Vitrification
T0818 TVIES, Inc., Soil Washing
T0819 U.S. Department of Energy Laboratories, Enhanced Sludge Washing
T0823 U.S. Filter Corporation, PO*WW*ER Wastewater Treatment System
T0828 U.S. Geologic Survey, Enzymatic Reduction of Uranium
T0830 U.S. Naval Academy, Air Classifier with Removal of Metals from Soil
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0850 UOP, Ionsiv IE-911 Ion Exchange Resins
T0851 UOP, TIE-96 Ion Exchange Resins
T0860 Viatec Recovery Systems, Inc., Waste Acid Detoxification and Reclamation
T0862 Vortec Corporation, Cyclone Melting System (CMS)
T0866 Washington Group International and Spetstamponazhgeologia Enterprises, Clay-Based Grouting Technique
T0883 Westinghouse Savannah River Company, Countercurrent Decanting
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0887 Westinghouse Savannah River Corporation, Transportable Vitrification System
T0888 Wet Oxidation—General
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process

RADIUM

T0001 3M Company, 3M Empore Extraction Disk
T0014 Advanced Recovery Systems, Inc., DeCaF
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0088 Battelle Pacific Northwest National Laboratory, Terra-VIT Vitrification Technology
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0298 Eriksson Sediment Systems, Inc., Eriksson System
T0344 Geosafe Corporation, In Situ Vitrification
T0452 Joule-Heated Vitrification—General
T0466 Krudico, Inc., Ion Exchange Resins for Nitrate and Perchlorate
T0546 Natural Attenuation—General
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0719 Soil/Sediment Washing—General
T0767 TechTran Environmental, Inc., RHM-1000 Process
T0772 Terra Vac, Geochemical Fixation
T0798 Thermo Nuclean, Segmented Gate System (SGS)
T0818 TVIES, Inc., Soil Washing
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process

RING-SUBSTITUTED AROMATICS

Chlorobenzene; Monochlorobenzene

T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0126 Bioventing—General
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0178 Constructed Wetlands—General
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0221 Eagle Environmental Technologies, Ltd., Plasma Technique
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment

T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0253 Energy Reclamation, Inc., Pyrolytic Waste Reclamation (PWR)
T0329 General Atomics, Supercritical Water Oxidation
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0355 Granular Activated Carbon (GAC)—General
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0373 Horizontal Drilling—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0459 King, Buck Technologies, Inc., HD CatOx System
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0529 Millgard Corporation, MecTool Remediation System
T0531 Mirage Systems, Inc., ChemChar Process
T0536 Molten Salt Oxidation—General
T0546 Natural Attenuation—General
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0592 Passive Soil Vapor Extraction—General
T0613 Plasma Vitrification—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0668 Rochem Environmental, Inc., Disc Tube
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0756 Supercritical Water Oxidation—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0787 Texaco, Inc., Texaco Gasification Process
T0794 Thermal Desorption—General
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0799 ThermoChem, Inc., PulseEnhanced Steam Reformer
T0805 ThermoRetec, Thermatek Thermal Desorption
T0807 Thorneco, Inc., Enzyme-Activated Cellulose Technology
T0817 T-Thermal Company, Submerged Quench Incineration
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0891 Williams Environmental, RamSorb-1
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Chlorotoluene, 2

T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure

T0329 General Atomics, Supercritical Water Oxidation
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0613 Plasma Vitrification—General
T0756 Supercritical Water Oxidation—General

DDD; Dichloro(chlorophenyl)-bis Ethane

T0001 3M Company, 3M Empore Extraction Disk
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0452 Joule-Heated Vitrification—General
T0499 Maxymillian Technologies, Inc., Indirect System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0601 Permeable Reactive Barriers (PRBs)—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0732 Solvent Extraction—General
T0755 Supercritical Carbon Dioxide Extraction—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0889 White-Rot Fungus—General

DDE; Dichlorodiphenyldichloroethylene

T0001 3M Company, 3M Empore Extraction Disk
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0452 Joule-Heated Vitrification—General

T0499 Maxymillian Technologies, Inc., Indirect System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0509 Metal-Based Permeable Reactive Barriers—General
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0579 On-Site Thermal Services Division of Soil Restoration and Recycling, L.L.C., Low-Temperature Thermal Desorption Plant
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0715 Smith Technology Corporation Low-Temperature Thermal Aeration (LTTA)
T0732 Solvent Extraction—General
T0755 Supercritical Carbon Dioxide Extraction—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0868 Waste Management, Inc., X*TRAX Thermal Desorption

Dichlorobenzene, 1,2

T0024 Air Stripping—General
T0126 Bioventing—General
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0259 ENSR International Group, Biovault
T0320 Funderburk & Associates, Solidification Process
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0453 Kaiser-Hill Company, L.L.C., Supercritical Carbon Dioxide Extraction
T0459 King, Buck Technologies, Inc., HD CatOx System
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0529 Millgard Corporation, MecTool Remediation System
T0546 Natural Attenuation—General
T0613 Plasma Vitrification—General
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0661 Reverse Osmosis—General
T0668 Rochem Environmental, Inc., Disc Tube
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0693 SCC Environmental, Thermal-Phase Separation Unit

T0696 Science Applications International Corporation, Plasma Hearth Process
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0794 Thermal Desorption—General
T0799 ThermoChem, Inc., PulseEnhanced Steam Reformer
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0871 WASTECH, Inc., Solidification and Stabilization
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Dichlorobenzene, 1,3

T0126 Bioventing—General
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0259 ENSR International Group, Biovault
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0546 Natural Attenuation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0756 Supercritical Water Oxidation—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0794 Thermal Desorption—General
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0871 WASTECH, Inc., Solidification and Stabilization
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Dichlorobenzene, 1,4

T0005 Active Environmental Technologies, Inc., TechXtract
T0126 Bioventing—General
T0161 Chemical Oxidation—General
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0259 ENSR International Group, Biovault
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC

T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0756 Supercritical Water Oxidation—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0794 Thermal Desorption—General
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0871 WASTECH, Inc., Solidification and Stabilization
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Hexachlorobenzene

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0138 Calgon Carbon Corporation, Perox-Pure
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0200 Delphi Research, Inc., DETOX
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0344 Geosafe Corporation, In Situ Vitrification
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0449 IT Corporation, Thermal Desorption
T0450 IT Corporation, Thermal Destruction Unit
T0487 Louisiana State University, Colloidal Gas Aphron
T0531 Mirage Systems, Inc., ChemChar Process
T0536 Molten Salt Oxidation—General
T0546 Natural Attenuation—General
T0594 PEAT, Inc., Thermal Destruction and Recovery
T0601 Permeable Reactive Barriers (PRBs)—General
T0613 Plasma Vitrification—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0755 Supercritical Carbon Dioxide Extraction—General
T0794 Thermal Desorption—General
T0901 Zeros USA, Inc., Zero-Emission Energy Recycling System (ZEROS)

Polychlorinated Benzenes

T0011 Advanced Microbial Solutions, SuperBio
T0108 Biomin, Inc., Organoclay
T0166 Cintec Environment, Inc. Circulating Fluidized-Bed Combustor (CFBC)
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)

T0236 Electrokinetic Remediation—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0487 Louisiana State University, Colloidal Gas Aphron
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0867 Waste Management, Inc., DeChlor/KGME Process

Polychlorinated Biphenyls; PCBs; Aroclor

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0053 ARCADIS Geraghty and Miller, Inc., STRATEX (Stratified Temperature Extractor)
T0055 Arctech, Inc., Bioremediation—Solid Phase
T0056 Arctech, Inc., Light-Activated Reduction of Chemicals (LARC)
T0058 Arctic Foundations, Inc., Cryogenic Barrier
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0075 B & S Research, Inc., B&S Achieve-B&S Industrial
T0082 Battelle Memorial Institute Universal Demercurization Process (UNIDEMP)
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0100 BioGenesis Enterprises, Inc., Soil Remediation and Cleaning Products
T0101 Bio-Genesis Technologies, Aerobic Biotreatment System (ABS)
T0108 Biomin, Inc., Organoclay
T0114 Bioremediation Technology Services, Inc., BTS Method
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0124 BioTrol, Inc., Soil Washing Technology
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0143 Carson Environmental, Low-Temperature Oxidation
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0149 Cement-Based Stabilization/Solidification—General
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process

T0200 Delphi Research, Inc., DETOX
T0202 Detox Industries, Inc., DETOX Process
T0204 Distillation—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0220 E.W.M.C. International, Inc., Emery Microwave Process
T0221 Eagle Environmental Technologies, Ltd., Plasma Technique
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0228 ECO-TEC, Inc., EnviroMech Gold Biocatalytic Contaminant Degradation
T0236 Electrokinetic Remediation—General
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0253 Energy Reclamation, Inc., Pyrolytic Waste Reclamation (PWR)
T0260 ENSR International Group, Soil Cleaning Process
T0266 Envirogen, Inc., Solid Organic-Phase Extraction (SoPE)
T0272 Environment Canada, Microwave-Assisted Process
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0286 Environmental Treatment and Technologies Corporation, Methanol Extraction Process
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0298 Eriksson Sediment Systems, Inc., Eriksson System
T0299 ETG Environmental, Inc., Thermo-O-Detox Medium-Temperature Thermal Desorption (MTTD)
T0300 ETUS, Inc., Enhanced Bioremediation
T0303 Extraksol (vendor unknown)
T0304 F2 Associates, Inc., Laser Ablation
T0309 Fixed-Bed Soil Biofilters—General
T0310 Fluidized-Bed Thermal Oxidation—General
T0313 Forrester Environmental Services, Inc., Stabilization of Lead-Bearing Waste
T0320 Funderburk & Associates, Solidification Process
T0321 Fungi Perfecti, Mycova Mycoremediation and Mycofiltration
T0323 G.E.M., Inc., Chemical Treatment
T0325 Galson Remediation Corporation, APEG-PLUS Process
T0327 General Atomics, Circulating Bed Combustor (CBC)
T0329 General Atomics, Supercritical Water Oxidation
T0330 General Electric Company, Thermal Heating Blanket
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0335 Geo-Con, Inc., Deep Soil Mixing
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0348 GHEA Associates, Soil Washing Technology
T0355 Granular Activated Carbon (GAC)—General
T0357 GSE Lining Technology, Inc., GSE CurtainWall Vertical Membrane Barrier System
T0358 GSE Lining Technology, Inc., GSE GundWall Vertical Membrane Barrier Systems
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0403 IM-TECH, Solidification/Stabilization Process
T0404 In Situ Grouting—General
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC

T0410 Institute of Gas Technology, AGGCOM
T0411 Institute of Gas Technology, Fluid Extraction—Biological Degradation
T0412 Institute of Gas Technology, MGP-REM
T0413 Institute of Gas Technology, PCB-REM Process
T0414 Institute of Gas Technology, SELPhOx
T0416 Intech One Eighty, White-Rot Fungus
T0417 Integrated Chemistries, Inc., Capsur
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0446 IT Corporation, Photolytic and Biological Soil Detoxification
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0450 IT Corporation, Thermal Destruction Unit
T0451 J.M. Huber Corporation, Advanced Electric Reactor
T0452 Joule-Heated Vitrification—General
T0453 Kaiser-Hill Company, L.L.C., Supercritical Carbon Dioxide Extraction
T0461 Kinit Enterprises, Trozone Soil Remediation System
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0472 Lawrence Livermore National Laboratory, Destruction of Polychlorinated Biphenyls Using High-Energy Ionizing Radiation
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0483 Lockheed Martin Energy Systems, Inc., Soilex Process
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0499 Maxymillian Technologies, Inc., Indirect System
T0501 MBI International, Anaerobic PCB Dechlorinating Granular Consortia
T0516 Metcalf & Eddy, Inc., ORG-X
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0529 Millgard Corporation, MecTool Remediation System
T0531 Mirage Systems, Inc., ChemChar Process
T0532 Modified Natural Clays—General
T0536 Molten Salt Oxidation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0542 Mycotech Corporation, Fungal Bioremediation
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0604 Philip Environmental Services Corporation, Thermal Recycling System
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0612 Plasma Environmental Technologies, Inc., Plasma Arcing Conversion (PARCON) Unit
T0613 Plasma Vitrification—General
T0616 Pozzolanic Solidification/Stabilization—General
T0618 Praxair, Inc., MixFlo
T0619 Praxair, Inc., Oxygen Combustion System
T0622 Pressure Systems, Inc., Phoenix Ash Technology

T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0632 Pyrolysis—General
T0633 Pyrovac International, Inc., Pyrocycling Process
T0638 R.E. Wright Environmental, Inc., Steam-Enhanced Recovery
T0642 Recol Engineering, Ltd., RYMOX Technology
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0677 Rust Federal Services, Inc., VAC*TRAX Thermal Desorption
T0679 S.M.W. Seiko, Inc., Soil–Cement Mixing Wall
T0680 S.S. Papadopulos & Associates, Inc., DeNAPLs (Detergent Extraction of NAPLs)
T0681 Safety-Kleen Corporation, PPM Dechlorination Process
T0685 Sanexen Environmental Services, Inc., Decontaksolv
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0689 SBP Technologies, Inc., Membrane Filtration
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0699 SDTX Technologies, Inc., KPEG
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0711 Shirco Infrared Systems, Inc., Shirco Infrared Thermal Destruction System
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0719 Soil/Sediment Washing—General
T0721 Soil Flushing—General
T0723 Soil Technology, Inc., Remediation Technologies Using Electrolytically Produced Water
T0724 Soil Technology, Inc., Soil Washing Treatability Study Unit
T0726 Solidification/Stabilization—General
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0728 Solox, Hybrid Solar/Electric Ultraviolet Oxidation System
T0732 Solvent Extraction—General
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0753 Summit Research Corporation, Supercritical Water Oxidation
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0759 Surfactants—General
T0762 Syracuse University, Supercritical Fluid Extraction
T0769 Terra Resources, Ltd., Terra Wash Soil Washing
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells

T0787 Texaco, Inc., Texaco Gasification Process
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0817 T-Thermal Company, Submerged Quench Incineration
T0821 U.S. EPA and IT Corporation, Debris Washing System
T0822 U.S. EPA National Risk Management Research Laboratory, Base-Catalyzed Decomposition
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0842 University of California, Riverside, Carvone-Induced Bioremediation
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0853 UV Technologies, Inc., UV-CATOX Technology
T0862 Vortec Corporation, Cyclone Melting System (CMS)
T0867 Waste Management, Inc., DeChlor/KGME Process
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0871 WASTECH, Inc., Solidification and Stabilization
T0888 Wet Oxidation—General
T0889 White-Rot Fungus—General
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0893 WRS Infrastructure & Environmental, Inc., Thermal Desorption Unit
T0895 Xetex Corporation, XeChlor Process
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat
T0901 Zeros USA, Inc., Zero-Emission Energy Recycling System (ZEROS)

Ring-Substituted Aromatics

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0053 ARCADIS Geraghty and Miller, Inc., STRATEX (Stratified Temperature Extractor)
T0055 Arctech, Inc., Bioremediation—Solid Phase
T0056 Arctech, Inc., Light-Activated Reduction of Chemicals (LARC)
T0058 Arctic Foundations, Inc., Cryogenic Barrier
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0075 B & S Research, Inc., B&S Achieve-B&S Industrial
T0082 Battelle Memorial Institute, Universal Demercurization Process (UNIDEMP)
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0100 BioGenesis Enterprises, Inc., Soil Remediation and Cleaning Products

T0101 Bio-Genesis Technologies, Aerobic Biotreatment System (ABS)
T0108 Biomin, Inc., Organoclay
T0114 Bioremediation Technology Services, Inc., BTS Method
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0143 Carson Environmental, Low-Temperature Oxidation
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0149 Cement-Based Stabilization/Solidification—General
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0168 CleanSoil, Inc., CleanSoil Process
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0178 Constructed Wetlands—General
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0200 Delphi Research, Inc., DETOX
T0202 Detox Industries, Inc., DETOX Process
T0204 Distillation—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0220 E.W.M.C. International, Inc., Emery Microwave Process
T0221 Eagle Environmental Technologies, Ltd., Plasma Technique
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0228 ECO-TEC, Inc., EnviroMech Gold Biocatalytic Contaminant Degradation
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0253 Energy Reclamation, Inc., Pyrolytic Waste Reclamation (PWR)
T0259 ENSR International Group, Biovault
T0260 ENSR International Group, Soil Cleaning Process
T0266 Envirogen, Inc., Solid Organic Phase Extraction (SoPE)
T0272 Environment Canada, Microwave-Assisted Process
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0286 Environmental Treatment and Technologies Corporation, Methanol Extraction Process
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0298 Eriksson Sediment Systems, Inc., Eriksson System

T0299 ETG Environmental, Inc., Thermo-O-Detox Medium-Temperature Thermal Desorption (MTTD)
T0300 ETUS, Inc., Enhanced Bioremediation
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0303 Extraksol (vendor unknown)
T0304 F2 Associates, Inc., Laser Ablation
T0309 Fixed-Bed Soil Biofilters—General
T0310 Fluidized-Bed Thermal Oxidation—General
T0313 Forrester Environmental Services, Inc., Stabilization of Lead-Bearing Waste
T0320 Funderburk & Associates, Solidification Process
T0321 Fungi Perfecti, Mycova Mycoremediation and Mycofiltration
T0323 G.E.M., Inc., Chemical Treatment
T0325 Galson Remediation Corporation, APEG-PLUS Process
T0327 General Atomics, Circulating Bed Combustor (CBC)
T0329 General Atomics, Supercritical Water Oxidation
T0330 General Electric Company, Thermal Heating Blanket
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0335 Geo-Con, Inc., Deep Soil Mixing
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0357 GSE Lining Technology, Inc., GSE CurtainWall Vertical Membrane Barrier System
T0358 GSE Lining Technology, Inc., GSE GundWall Vertical Membrane Barrier Systems
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0403 IM-TECH, Solidification/Stabilization Process
T0404 In Situ Grouting—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0410 Institute of Gas Technology, AGGCOM
T0411 Institute of Gas Technology, Fluid Extraction—Biological Degradation
T0412 Institute of Gas Technology, MGP-REM
T0413 Institute of Gas Technology, PCB-REM Process
T0414 Institute of Gas Technology, SELPhOx
T0416 Intech One Eighty, White-Rot Fungus
T0417 Integrated Chemistries, Inc., Capsur
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0446 IT Corporation, Photolytic and Biological Soil Detoxification

T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0450 IT Corporation, Thermal Destruction Unit
T0451 J.M. Huber Corporation, Advanced Electric Reactor
T0452 Joule-Heated Vitrification—General
T0453 Kaiser-Hill Company, L.L.C., Supercritical Carbon Dioxide Extraction
T0459 King, Buck Technologies, Inc., HD CatOx System
T0461 Kinit Enterprises, Trozone Soil Remediation System
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0472 Lawrence Livermore National Laboratory, Destruction of Polychlorinated Biphenyls Using High-Energy Ionizing Radiation
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0483 Lockheed Martin Energy Systems, Inc., Soilex Process
T0487 Louisiana State University, Colloidal Gas Aphron
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0499 Maxymillian Technologies, Inc., Indirect System
T0501 MBI International, Anaerobic PCB Dechlorinating Granular Consortia
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0509 Metal-Based Permeable Reactive Barriers—General
T0516 Metcalf & Eddy, Inc., ORG-X
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0529 Millgard Corporation, MecTool Remediation System
T0531 Mirage Systems, Inc., ChemChar Process
T0532 Modified Natural Clays—General
T0536 Molten Salt Oxidation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0542 Mycotech Corporation, Fungal Bioremediation
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0579 On-Site Thermal Services Division of Soil Restoration and Recycling, L.L.C., Low-Temperature Thermal Desorption Plant
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0592 Passive Soil Vapor Extraction—General
T0594 PEAT, Inc., Thermal Destruction and Recovery
T0601 Permeable Reactive Barriers (PRBs)—General
T0604 Philip Environmental Services Corporation, Thermal Recycling System
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0612 Plasma Environmental Technologies, Inc., Plasma Arcing Conversion (PARCON) Unit
T0613 Plasma Vitrification—General
T0616 Pozzolanic Solidification/Stabilization—General
T0618 Praxair, Inc., MixFlo

T0619 Praxair, Inc., Oxygen Combustion System
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0632 Pyrolysis—General
T0633 Pyrovac International, Inc., Pyrocycling Process
T0638 R.E. Wright Environmental, Inc., Steam-Enhanced Recovery
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0642 Recol Engineering, Ltd., RYMOX Technology
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0661 Reverse Osmosis—General
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0668 Rochem Environmental, Inc., Disc Tube
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0677 Rust Federal Services, Inc., VAC*TRAX Thermal Desorption
T0679 S.M.W. Seiko, Inc., Soil–Cement Mixing Wall
T0680 S.S. Papadopulos & Associates, Inc., DeNAPLs (Detergent Extraction of NAPLs)
T0681 Safety-Kleen Corporation, PPM Dechlorination Process
T0685 Sanexen Environmental Services, Inc., Decontaksolv
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0689 SBP Technologies, Inc., Membrane Filtration
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0696 Science Applications International Corporation, Plasma Hearth Process
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0699 SDTX Technologies, Inc., KPEG
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0711 Shirco Infrared Systems, Inc., Shirco Infrared Thermal Destruction System
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0719 Soil/Sediment Washing—General
T0721 Soil Flushing—General
T0723 Soil Technology, Inc., Remediation Technologies Using Electrolytically Produced Water
T0724 Soil Technology, Inc., Soil Washing Treatability Study Unit
T0726 Solidification/Stabilization—General
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0728 Solox, Hybrid Solar/Electric Ultraviolet Oxidation System
T0732 Solvent Extraction—General
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)

T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0753 Summit Research Corporation, Supercritical Water Oxidation
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0759 Surfactants—General
T0762 Syracuse University, Supercritical Fluid Extraction
T0769 Terra Resources, Ltd., Terra Wash Soil Washing
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0779 Terra Vac, Inc., Vacuum Extraction
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0799 ThermoChem, Inc., PulseEnhanced Steam Reformer
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0807 Thorneco, Inc., Enzyme-Activated Cellulose Technology
T0817 T-Thermal Company, Submerged Quench Incineration
T0821 U.S. EPA and IT Corporation, Debris Washing System
T0822 U.S. EPA National Risk Management Research Laboratory, Base-Catalyzed Decomposition
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0842 University of California, Riverside, Carvone-Induced Bioremediation
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0862 Vortec Corporation, Cyclone Melting System (CMS)
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0867 Waste Management, Inc., DeChlor/KGME Process
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0871 WASTECH, Inc., Solidification and Stabilization
T0888 Wet Oxidation—General
T0889 White-Rot Fungus—General
T0891 Williams Environmental, RamSorb-1
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0893 WRS Infrastructure & Environmental, Inc., Thermal Desorption Unit
T0895 Xetex Corporation, XeChlor Process
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat

T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System
T0901 Zeros USA, Inc., Zero-Emission Energy Recycling System (ZEROS)

Tetrachlorobenzene

T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0755 Supercritical Carbon Dioxide Extraction—General
T0794 Thermal Desorption—General

Trichlorobenzene, 1,2,4

T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0126 Bioventing—General
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0320 Funderburk & Associates, Solidification Process
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0453 Kaiser-Hill Company, L.L.C., Supercritical Carbon Dioxide Extraction
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0536 Molten Salt Oxidation—General
T0607 Phytoremediation—General
T0619 Praxair, Inc., Oxygen Combustion System
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)

SATURATED ALKYL HALIDES

Bromodichloromethane

T0024 Air Stripping—General
T0138 Calgon Carbon Corporation, Perox-Pure

T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Bromoform; Tribromomethane

T0024 Air Stripping—General
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Butyl Chloride; Chlorobutane

T0355 Granular Activated Carbon (GAC)—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

Carbon Tetrachloride

T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0024 Air Stripping—General
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0054 Arctech, Inc., Humasorb
T0063 Argonne National Laboratory, In-Well Sonication
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0084 Battelle Pacific Northwest Laboratory, Gas-Phase Corona Reactor
T0087 Battelle Pacific Northwest National Laboratory, Liquid Corona
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0168 CleanSoil, Inc., CleanSoil Process
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0198 Davis Environmental, Multistage In-Well Aerator
T0200 Delphi Research, Inc., DETOX
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process

T0275 Environmental Fuel Systems, Inc., Reclaim
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0310 Fluidized-Bed Thermal Oxidation—General
T0320 Funderburk & Associates, Solidification Process
T0329 General Atomics, Supercritical Water Oxidation
T0335 Geo-Con, Inc., Deep Soil Mixing
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0373 Horizontal Drilling—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0404 In Situ Grouting—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0416 Intech One Eighty, White-Rot Fungus
T0453 Kaiser-Hill Company, L.L.C., Supercritical Carbon Dioxide Extraction
T0459 King, Buck Technologies, Inc., HD CatOx System
T0468 KVA, C-Sparger System
T0487 Louisiana State University, Colloidal Gas Aphron
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0494 ManTech Environmental Corporation, CleanOX Process
T0497 Massachusetts Institute of Technology, Tunable Hybrid Plasma
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General
T0544 National Renewable Energy Laboratory Solar Detoxification of Water
T0546 Natural Attenuation—General
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0582 Onyx Industrial Services, SOIL*EX
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0586 Pacific Northwest National Laboratory, In Situ Redox Manipulation
T0592 Passive Soil Vapor Extraction—General
T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0613 Plasma Vitrification—General
T0619 Praxair, Inc., Oxygen Combustion System
T0627 *Pseudomonas* sp. Strain KC—General
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0631 Purus, Inc., Pulsed UV Irradiation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0695 Science & Engineering Associates, Inc., Barometrically Enhanced Remediation Technology (BERT)

T0696 Science Applications International Corporation, Plasma Hearth Process
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0711 Shirco Infrared Systems, Inc., Shirco Infrared Thermal Destruction System
T0721 Soil Flushing—General
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0771 Terra Vac, DNAPL Vaporization
T0779 Terra Vac, Inc., Vacuum Extraction
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0817 T-Thermal Company, Submerged Quench Incineration
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0841 University of Akron, Sonochemical Destruction
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0855 Vapor-Phase Biofiltration—General
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0889 White-Rot Fungus—General
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Carbon Tetrafluoride

T0032 Alzeta Corporation, EDGE Thermal Processing Units
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma

Chloroform; Trichloromethane

T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0054 Arctech, Inc., Humasorb
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0108 Biomin, Inc., Organoclay
T0114 Bioremediation Technology Services, Inc., BTS Method
T0125 BioTrol, Inc., Methanotropic Bioreactor System
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox

T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0198 Davis Environmental, Multistage In-Well Aerator
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0310 Fluidized-Bed Thermal Oxidation—General
T0320 Funderburk & Associates, Solidification Process
T0329 General Atomics, Supercritical Water Oxidation
T0335 Geo-Con, Inc., Deep Soil Mixing
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0459 King, Buck Technologies, Inc., HD CatOx System
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0546 Natural Attenuation—General
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0631 Purus, Inc., Pulsed UV Irradiation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0695 Science & Engineering Associates, Inc., Barometrically Enhanced Remediation Technology (BERT)
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0771 Terra Vac, DNAPL Vaporization
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0807 Thorneco, Inc., Enzyme-Activated Cellulose Technology
T0817 T-Thermal Company, Submerged Quench Incineration
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0841 University of Akron, Sonochemical Destruction
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0889 White-Rot Fungus—General
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Chloromethane; Methyl Chloride

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0334 Geo-Con, Inc., Shallow Soil Mixing/Thermally Enhanced Vapor Extraction
T0355 Granular Activated Carbon (GAC)—General
T0494 ManTech Environmental Corporation, CleanOX Process
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Dibromochloromethane

T0138 Calgon Carbon Corporation, Perox-Pure
T0168 CleanSoil, Inc., CleanSoil Process
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)

Dibromoethane, 1,2; Ethylene Dibromide

T0024 Air Stripping—General
T0063 Argonne National Laboratory, In-Well Sonication
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0127 Blast Fracturing—General
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0355 Granular Activated Carbon (GAC)—General

T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0607 Phytoremediation—General

Dibromomethane

T0024 Air Stripping—General
T0138 Calgon Carbon Corporation, Perox-Pure
T0355 Granular Activated Carbon (GAC)—General
T0384 Hydraulic Fracturing—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction

Dichlorodifluoromethane; Freon 12

T0024 Air Stripping—General
T0138 Calgon Carbon Corporation, Perox-Pure
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0198 Davis Environmental, Multistage In-Well Aerator
T0355 Granular Activated Carbon (GAC)—General
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0756 Supercritical Water Oxidation—General
T0780 Terra Vac, Soil Heating

Dichloroethane, 1,1

T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0125 BioTrol, Inc., Methanotropic Bioreactor System
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0258 ENSR International Group, Anaerobic Biotransformation with Steam Injection
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0310 Fluidized-Bed Thermal Oxidation—General
T0334 Geo-Con Inc., Shallow Soil Mixing/Thermally Enhanced Vapor Extraction
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0374 Horizontal Technologies, Inc., Linear Containment Remediation System
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0509 Metal-Based Permeable Reactive Barriers—General
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0592 Passive Soil Vapor Extraction—General

T0629 Pulse Sciences, Inc., X-Ray Treatment
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0771 Terra Vac, DNAPL Vaporization
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Dichloroethane, 1,2; DCA

T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0198 Davis Environmental, Multistage In-Well Aerator
T0236 Electrokinetic Remediation—General
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0355 Granular Activated Carbon (GAC)—General
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0373 Horizontal Drilling—General
T0384 Hydraulic Fracturing—General
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0450 IT Corporation, Thermal Destruction Unit
T0459 King, Buck Technologies, Inc., HD CatOx System
T0467 KSE, Inc., AIR-II Process
T0487 Louisiana State University, Colloidal Gas Aphron
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0497 Massachusetts Institute of Technology, Tunable Hybrid Plasma
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General
T0537 Monsanto Company, Lasagna
T0546 Natural Attenuation—General

T0573 O'Brien & Gere Engineers, Inc., Mechanical Volatilization Screening
T0613 Plasma Vitrification—General
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0670 Rohm and Haas Company, Amberlite XAD-4
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0755 Supercritical Carbon Dioxide Extraction—General
T0771 Terra Vac, DNAPL Vaporization
T0774 Terra Vac, Inc., Biovac
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0803 ThermoRetec, Prepared Bed Bioremediation
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0841 University of Akron, Sonochemical Destruction
T0853 UV Technologies, Inc., UV-CATOX Technology
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Dichloropropane, 1,2

T0138 Calgon Carbon Corporation, Perox-Pure
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0546 Natural Attenuation—General
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0794 Thermal Desorption—General
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Dichlorotrifluoroethane; HCFC-1,2,3

T0406 In Situ Soil Vapor Extraction (SVE)—General
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System

Ethyl Chloride; Chloroethane

T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0258 ENSR International Group, Anaerobic Biotransformation with Steam Injection
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0355 Granular Activated Carbon (GAC)—General

T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0374 Horizontal Technologies, Inc., Linear Containment Remediation System
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0459 King, Buck Technologies, Inc., HD CatOx System
T0494 ManTech Environmental Corporation, CleanOX Process
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0661 Reverse Osmosis—General
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

Freon 111

T0780 Terra Vac, Soil Heating
T0796 Thermatrix, Inc., PADRE Air Treatment Systems

Freon 113

T0024 Air Stripping—General
T0161 Chemical Oxidation—General
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0494 ManTech Environmental Corporation, CleanOX Process
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0529 Millgard Corporation, MecTool Remediation System
T0601 Permeable Reactive Barriers (PRBs)—General
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0631 Purus, Inc., Pulsed UV Irradiation
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0774 Terra Vac, Inc., Biovac
T0780 Terra Vac, Soil Heating
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0894 Xerox Corporation, Two-Phase Extraction System

Hexachlorocyclohexane; Lindane

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0320 Funderburk & Associates, Solidification Process
T0323 G.E.M., Inc., Chemical Treatment
T0329 General Atomics, Supercritical Water Oxidation

T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0416 Intech One Eighty, White-Rot Fungus
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0822 U.S. EPA National Risk Management Research Laboratory, Base-Catalyzed Decomposition
T0889 White Rot Fungus—General

Hexachloroethane

T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0487 Louisiana State University, Colloidal Gas Aphron
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0619 Praxair, Inc., Oxygen Combustion System

Hexafluoroethane

T0032 Alzeta Corporation, EDGE Thermal Processing Units
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma

Methyl Bromide; Bromomethane

T0024 Air Stripping—General
T0161 Chemical Oxidation—General
T0459 King, Buck Technologies, Inc., HD CatOx System
T0494 ManTech Environmental Corporation, CleanOX Process
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0775 Terra Vac, Inc., Dual-Vacuum Extraction

Methylene Chloride; Dichloromethane

T0011 Advanced Microbial Solutions, SuperBio
T0021 Aeromix Systems, Inc., BREEZE

T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0108 Biomin, Inc., Organoclay
T0114 Bioremediation Technology Services, Inc., BTS Method
T0125 BioTrol, Inc., Methanotropic Bioreactor System
T0127 Blast Fracturing—General
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0212 Dual-Phase Extraction—General
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0259 ENSR International Group, Biovault
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0320 Funderburk & Associates, Solidification Process
T0329 General Atomics, Supercritical Water Oxidation
T0335 Geo-Con, Inc., Deep Soil Mixing
T0355 Granular Activated Carbon (GAC)—General
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0459 King, Buck Technologies, Inc., HD CatOx System
T0467 KSE, Inc., AIR-II Process
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0533 Molasses Treatment for Bioremediation—General
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0546 Natural Attenuation—General
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0566 NUCON International, Inc., Brayton Cycle
T0607 Phytoremediation—General
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0631 Purus, Inc., Pulsed UV Irradiation

T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0771 Terra Vac, DNAPL Vaporization
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0807 Thorneco, Inc., Enzyme-Activated Cellulose Technology
T0820 U.S. Environmental Protection Agency, Reductive Anaerobic Biological In Situ Treatment (RABIT)
T0823 U.S. Filter Corporation, PO*WW*ER Wastewater Treatment System
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0841 University of Akron, Sonochemical Destruction
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0889 White-Rot Fungus—General
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Saturated Alkyl Halides

T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0032 Alzeta Corporation, EDGE Thermal Processing Units
T0044 Applied Natural Sciences, Inc., TreeMediation
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0054 Arctech, Inc., Humasorb
T0063 Argonne National Laboratory, In-Well Sonication
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0084 Battelle Pacific Northwest Laboratory, Gas-Phase Corona Reactor
T0087 Battelle Pacific Northwest National Laboratory, Liquid Corona

T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0108 Biomin, Inc., Organoclay
T0114 Bioremediation Technology Services, Inc., BTS Method
T0125 BioTrol, Inc., Methanotropic Bioreactor System
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0161 Chemical Oxidation—General
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0168 CleanSoil, Inc., CleanSoil Process
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0198 Davis Environmental, Multistage In-Well Aerator
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0200 Delphi Research, Inc., DETOX
T0212 Dual-Phase Extraction—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0258 ENSR International Group, Anaerobic Biotransformation with Steam Injection
T0259 ENSR International Group, Biovault
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0275 Environmental Fuel Systems, Inc., Reclaim
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0310 Fluidized-Bed Thermal Oxidation—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0323 G.E.M., Inc., Chemical Treatment
T0329 General Atomics, Supercritical Water Oxidation
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0334 Geo-Con Inc., Shallow Soil Mixing/Thermally Enhanced Vapor Extraction
T0335 Geo-Con, Inc., Deep Soil Mixing
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0363 Harding ESE, Inc., PetroClean Bioremediation System

T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0374 Horizontal Technologies, Inc., Linear Containment Remediation System
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0400 IIT Research Institute, Radio Frequency Heating
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0404 In Situ Grouting—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0416 Intech One Eighty, White-Rot Fungus
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0450 IT Corporation, Thermal Destruction Unit
T0452 Joule-Heated Vitrification—General
T0453 Kaiser-Hill Company, L.L.C., Supercritical Carbon Dioxide Extraction
T0459 King, Buck Technologies, Inc., HD CatOx System
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0487 Louisiana State University, Colloidal Gas Aphron
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0494 ManTech Environmental Corporation, CleanOX Process
T0497 Massachusetts Institute of Technology, Tunable Hybrid Plasma
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General
T0537 Monsanto Company, Lasagna
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0546 Natural Attenuation—General
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology

T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0566 NUCON International, Inc., Brayton Cycle
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0573 O'Brien & Gere Engineers, Inc., Mechanical Volatilization Screening
T0582 Onyx Industrial Services, SOIL*EX
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0586 Pacific Northwest National Laboratory, In Situ Redox Manipulation
T0592 Passive Soil Vapor Extraction—General
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0613 Plasma Vitrification—General
T0619 Praxair, Inc., Oxygen Combustion System
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0627 *Pseudomonas* sp. Strain KC—General
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0631 Purus, Inc., Pulsed UV Irradiation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0661 Reverse Osmosis—General
T0663 Rizzo Associates, Inc., Chlorinated Solvent Cleanup (Butane Biostimulation Technology)
T0670 Rohm and Haas Company, Amberlite XAD-4
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0695 Science & Engineering Associates, Inc., Barometrically Enhanced Remediation Technology (BERT)
T0696 Science Applications International Corporation, Plasma Hearth Process
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0711 Shirco Infrared Systems, Inc., Shirco Infrared Thermal Destruction System
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0721 Soil Flushing—General
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)

T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0771 Terra Vac, DNAPL Vaporization
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0780 Terra Vac, Soil Heating
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0803 ThermoRetec, Prepared Bed Bioremediation
T0807 Thorneco, Inc., Enzyme-Activated Cellulose Technology
T0817 T-Thermal Company, Submerged Quench Incineration
T0820 U.S. Environmental Protection Agency, Reductive Anaerobic Biological In Situ Treatment (RABIT)
T0822 U.S. EPA National Risk Management Research Laboratory, Base-Catalyzed Decomposition
T0823 U.S. Filter Corporation, PO*WW*ER Wastewater Treatment System
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0841 University of Akron, Sonochemical Destruction
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0878 Weiss Associates, Acoustic-Enhanced Remediation
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0889 White-Rot Fungus—General
T0894 Xerox Corporation, Two-Phase Extraction System
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Tetrachloroethane, 1,1,2,2

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0044 Applied Natural Sciences, Inc., TreeMediation

T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0108 Biomin, Inc., Organoclay
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0310 Fluidized-Bed Thermal Oxidation—General
T0320 Funderburk & Associates, Solidification Process
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0487 Louisiana State University, Colloidal Gas Aphron
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0546 Natural Attenuation—General
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0755 Supercritical Carbon Dioxide Extraction—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Trichloroethane, 1,1,2

T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0044 Applied Natural Sciences, Inc., TreeMediation
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0310 Fluidized-Bed Thermal Oxidation—General
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0329 General Atomics, Supercritical Water Oxidation
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0373 Horizontal Drilling—General
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0453 Kaiser-Hill Company, L.L.C., Supercritical Carbon Dioxide Extraction
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0546 Natural Attenuation—General
T0573 O’Brien & Gere Engineers, Inc., Mechanical Volatilization Screening

T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Trichloroethane, 1,1,1; TCA

T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0032 Alzeta Corporation, EDGE Thermal Processing Units
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0054 Arctech, Inc., Humasorb
T0063 Argonne National Laboratory, In-Well Sonication
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0125 BioTrol, Inc., Methanotropic Bioreactor System
T0126 Bioventing—General
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0200 Delphi Research, Inc., DETOX
T0212 Dual-Phase Extraction—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0258 ENSR International Group, Anaerobic Biotransformation with Steam Injection
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0310 Fluidized-Bed Thermal Oxidation—General
T0329 General Atomics, Supercritical Water Oxidation
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0334 Geo-Con, Inc., Shallow Soil Mixing/Thermally Enhanced Vapor Extraction
T0335 Geo-Con, Inc., Deep Soil Mixing
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma

T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0374 Horizontal Technologies, Inc., Linear Containment Remediation System
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0400 IIT Research Institute, Radio Frequency Heating
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0442 IT Corporation, In Situ Air Sparging
T0450 IT Corporation, Thermal Destruction Unit
T0452 Joule-Heated Vitrification—General
T0459 King, Buck Technologies, Inc., HD CatOx System
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0494 ManTech Environmental Corporation, CleanOX Process
T0497 Massachusetts Institute of Technology, Tunable Hybrid Plasma
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0533 Molasses Treatment for Bioremediation—General
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0546 Natural Attenuation—General
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0573 O'Brien & Gere Engineers, Inc., Mechanical Volatilization Screening
T0592 Passive Soil Vapor Extraction—General
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0613 Plasma Vitrification—General
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0631 Purus, Inc., Pulsed UV Irradiation
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0663 Rizzo Associates, Inc., Chlorinated Solvent Cleanup (Butane Biostimulation Technology)
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0696 Science Applications International Corporation, Plasma Hearth Process

T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0756 Supercritical Water Oxidation—General
T0771 Terra Vac, DNAPL Vaporization
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0841 University of Akron, Sonochemical Destruction
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0878 Weiss Associates, Acoustic-Enhanced Remediation
T0889 White-Rot Fungus—General
T0894 Xerox Corporation, Two-Phase Extraction System
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Trichlorofluoromethane; Freon 11; Fluorocarbon 11

T0138 Calgon Carbon Corporation, Perox-Pure
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0355 Granular Activated Carbon (GAC)—General
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0497 Massachusetts Institute of Technology, Tunable Hybrid Plasma
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0756 Supercritical Water Oxidation—General
T0771 Terra Vac, DNAPL Vaporization
T0780 Terra Vac, Soil Heating
T0841 University of Akron, Sonochemical Destruction
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Trichloropropane, 1,2,3

T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0529 Millgard Corporation, MecTool Remediation System
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0779 Terra Vac, Inc., Vacuum Extraction

SECONDARY ALCOHOLS

Isobutyl Alcohol

T0320 Funderburk & Associates, Solidification Process
T0408 In-Situ Fixation, Inc., Dual Auger System
T0891 Williams Environmental, RamSorb-1

Propanol, 2; Isopropyl Alcohol; Isopropanol

T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0138 Calgon Carbon Corporation, Perox-Pure
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0467 KSE, Inc., AIR-II Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0617 PPC Biofilter, Biofiltration Systems
T0672 Rohm and Haas Company, Ambersorb 600
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0855 Vapor-Phase Biofiltration—General
T0891 Williams Environmental, RamSorb-1

Secondary Alcohols

T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0138 Calgon Carbon Corporation, Perox-Pure
T0236 Electrokinetic Remediation—General
T0320 Funderburk & Associates, Solidification Process
T0363 Harding ESE, Inc., PetroClean Bioremediation System

T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0467 KSE, Inc., AIR-II Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0617 PPC Biofilter, Biofiltration Systems
T0672 Rohm and Haas Company, Ambersorb 600
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0855 Vapor-Phase Biofiltration—General
T0891 Williams Environmental, RamSorb-1

SECONDARY ALIPHATIC AMINES

HMX, Octagen, Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazine

T0055 Arctech, Inc., Bioremediation—Solid Phase
T0112 Bioremediation of Explosives: Contaminated Soil—General
T0175 Composting—General
T0178 Constructed Wetlands—General
T0180 Constructed Wetlands for Explosives Contamination—General
T0309 Fixed-Bed Soil Biofilters—General
T0329 General Atomics, Supercritical Water Oxidation
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0395 Idaho Research Foundation, Inc., and White Shield, Inc., Simplot Anaerobic Biological Remediation (SABRE)
T0416 Intech One Eighty, White-Rot Fungus
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General
T0542 Mycotech Corporation, Fungal Bioremediation
T0546 Natural Attenuation—General
T0589 Pacific Northwest National Laboratory, Environmentally Benign Digestion Process (EBDP)
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0756 Supercritical Water Oxidation—General
T0825 U.S. Filter, Ultrox Peroxone Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0889 White-Rot Fungus—General

RDX, Cyclonite, Hexahydro-1,3,5-trinitro-1,3,5-triazine

T0055 Arctech, Inc., Bioremediation—Solid Phase
T0112 Bioremediation of Explosives: Contaminated Soil—General
T0138 Calgon Carbon Corporation, Perox-Pure

T0161 Chemical Oxidation—General
T0175 Composting—General
T0178 Constructed Wetlands—General
T0180 Constructed Wetlands for Explosives Contamination—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0309 Fixed-Bed Soil Biofilters—General
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0395 Idaho Research Foundation, Inc., and White Shield, Inc., Simplot Anaerobic Biological Remediation (SABRE)
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General
T0542 Mycotech Corporation, Fungal Bioremediation
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0546 Natural Attenuation—General
T0589 Pacific Northwest National Laboratory, Environmentally Benign Digestion Process (EBDP)
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0825 U.S. Filter, Ultrox Peroxone Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0839 United States Army Environmental Center (USAEC), Hot-Gas Decontamination (HGD)
T0853 UV Technologies, Inc., UV-CATOX Technology
T0889 White-Rot Fungus—General

Secondary Aliphatic Amines

T0055 Arctech, Inc., Bioremediation—Solid Phase
T0112 Bioremediation of Explosives: Contaminated Soil—General
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0175 Composting—General
T0178 Constructed Wetlands—General
T0180 Constructed Wetlands for Explosives Contamination—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0309 Fixed-Bed Soil Biofilters—General
T0329 General Atomics, Supercritical Water Oxidation
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process

T0395 Idaho Research Foundation, Inc., and White Shield, Inc., Simplot Anaerobic Biological Remediation (SABRE)
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General
T0542 Mycotech Corporation, Fungal Bioremediation
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0546 Natural Attenuation—General
T0589 Pacific Northwest National Laboratory, Environmentally Benign Digestion Process (EBDP)
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0756 Supercritical Water Oxidation—General
T0825 U.S. Filter, Ultrox Peroxone Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0839 United States Army Environmental Center (USAEC), Hot-Gas Decontamination (HGD)
T0853 UV Technologies, Inc., UV-CATOX Technology
T0889 White-Rot Fungus—General

SELENIUM

T0005 Active Environmental Technologies, Inc., TechXtract
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0060 Argonne National Laboratory, Aqueous Biphasic Extraction System
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0088 Battelle Pacific Northwest National Laboratory, Terra-VIT Vitrification Technology
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0169 Clemson University, Sintered Ceramic Stabilization
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0218 Dynaphore, Inc., Forager Sponge Technology
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0291 EnviroSource Technologies, Inc., Super Detox Process
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0320 Funderburk & Associates, Solidification Process
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0359 GTS Duratek, DuraMelter
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0443 IT Corporation, In Situ Geochemical Fixation
T0450 IT Corporation, Thermal Destruction Unit
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock

T0509 Metal-Based Permeable Reactive Barriers—General
T0510 Metals Recovery, Inc., Metals Leaching
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0519 Met-Chem, Metal Kleen B (MCB)
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0562 North American Technologies Group, Inc., System IV
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0608 Phytoremediation: Hyperaccumulation—General
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0613 Plasma Vitrification—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0624 Proactive Applied Solutions Corporation, LEADX
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0741 Stark Encapsulation, Inc., METLCAP Chemical Cement
T0742 Starmet Corporation, RocTec Stabilization
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0772 Terra Vac, Geochemical Fixation
T0773 Terra Vac, Heap Leaching
T0808 Toledo Engineering Company, Inc., High-Temperature Joule-Heated Vitrification
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0849 University of Washington, Metals Treatment by Adsorptive Filtration

SILICON COMPOUNDS—OTHER SIGNIFICANT

Hexamethyldisilicon

T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0855 Vapor-Phase Biofiltration—General

SILVER

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0023 Affinity Water Technologies, Advanced Affinity Chromatography
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0124 BioTrol Inc., Soil Washing Technology
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0149 Cement-Based Stabilization/Solidification—General

T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0162 Chemical Precipitation of Metals—General
T0170 Clyde Engineering, Service Metals Removal
T0174 Commodore Separation Technologies, Inc., Supported Liquid Membrane
T0207 Doe Run Company, TERRAMET Heavy-Metal Removal Technology
T0218 Dynaphore, Inc., Forager Sponge Technology
T0230 EET Corporation, Microwaste Waste Solidification
T0232 Eichrom Industries, Inc., Diphonix
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0279 Environmental Research and Development, Inc., Neutral Process for Heavy-Metals Removal
T0280 Environmental Research and Development, Inc., Ice Electrode
T0291 EnviroSource Technologies, Inc., Super Detox Process
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0320 Funderburk & Associates, Solidification Process
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0452 Joule-Heated Vitrification—General
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0510 Metals Recovery, Inc., Metals Leaching
T0519 Met-Chem, Metal Kleen B (MCB)
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0541 MYCELX Technologies Corporation, MYCELX
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0562 North American Technologies Group, Inc., System IV
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0613 Plasma Vitrification—General
T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System
T0615 Polymer-Based Solidification/Stabilization—General
T0616 Pozzolanic Solidification/Stabilization—General
T0624 Proactive Applied Solutions Corporation, LEADX
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0692 SCC Environmental, Micro-Flo
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0726 Solidification/Stabilization—General
T0730 Solucorp Industries, Ltd., Molecular Bonding System
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0741 Stark Encapsulation, Inc., METLCAP Chemical Cement
T0742 Starmet Corporation, RocTec Stabilization
T0773 Terra Vac, Heap Leaching

T0801 Thermoplastic Stabilization/Solidification—General
T0808 Toledo Engineering Company, Inc., High-Temperature Joule-Heated Vitrification
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat
T0899 Zenon Environmental Systems, Inc., ZenoGem

SIMPLE AROMATIC NITRO COMPOUNDS

Dinitrotoluene

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0112 Bioremediation of Explosives: Contaminated Soil—General
T0138 Calgon Carbon Corporation, Perox-Pure
T0175 Composting—General
T0178 Constructed Wetlands—General
T0180 Constructed Wetlands for Explosives Contamination—General
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0445 IT Corporation, Ozonation
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0533 Molasses Treatment for Bioremediation—General
T0546 Natural Attenuation—General
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0756 Supercritical Water Oxidation—General
T0800 ThermoEnergy Corporation, NitRem
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0877 Weatherly, Inc., AQUA CRITOX
T0889 White-Rot Fungus—General

Nitrobenzene

T0005 Active Environmental Technologies, Inc., TechXtract
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0114 Bioremediation Technology Services, Inc., BTS Method
T0135 Calgon Carbon Corporation, Activated Carbon
T0161 Chemical Oxidation—General
T0180 Constructed Wetlands for Explosives Contamination—General
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0329 General Atomics, Supercritical Water Oxidation
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0373 Horizontal Drilling—General

T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0408 In-Situ Fixation, Inc., Dual Auger System
T0546 Natural Attenuation—General
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0756 Supercritical Water Oxidation—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process

Simple Aromatic Nitro Compounds

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0055 Arctech, Inc., Bioremediation—Solid Phase
T0112 Bioremediation of Explosives: Contaminated Soil—General
T0113 Bioremediation Service, Inc., AquaPlant Biofilter System
T0114 Bioremediation Technology Services, Inc., BTS Method
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0175 Composting—General
T0178 Constructed Wetlands—General
T0180 Constructed Wetlands for Explosives Contamination—General
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0295 EOD Technology, Inc., Biotechnical Processing of Explosives
T0309 Fixed-Bed Soil Biofilters—General
T0329 General Atomics, Supercritical Water Oxidation
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0344 Geosafe Corporation, In Situ Vitrification
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation

T0373 Horizontal Drilling—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0395 Idaho Research Foundation, Inc., and White Shield, Inc., Simplot Anaerobic Biological Remediation (SABRE)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0408 In-Situ Fixation, Inc., Dual Auger System
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0445 IT Corporation, Ozonation
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General
T0542 Mycotech Corporation, Fungal Bioremediation
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0546 Natural Attenuation—General
T0589 Pacific Northwest National Laboratory, Environmentally Benign Digestion Process (EBDP)
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0756 Supercritical Water Oxidation—General
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0779 Terra Vac, Inc., Vacuum Extraction
T0800 ThermoEnergy Corporation, NitRem
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0839 United States Army Environmental Center (USAEC), Hot-Gas Decontamination (HGD)
T0853 UV Technologies, Inc., UV-CATOX Technology
T0877 Weatherly, Inc., AQUA CRITOX
T0889 White-Rot Fungus—General

Trinitrotoluene; TNT

T0011 Advanced Microbial Solutions, SuperBio
T0055 Arctech, Inc., Bioremediation—Solid Phase
T0112 Bioremediation of Explosives: Contaminated Soil—General
T0113 Bioremediation Service, Inc., AquaPlant Biofilter System
T0114 Bioremediation Technology Services, Inc., BTS Method
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0161 Chemical Oxidation—General
T0175 Composting—General
T0178 Constructed Wetlands—General

T0180 Constructed Wetlands for Explosives Contamination—General
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0295 EOD Technology, Inc., Biotechnical Processing of Explosives
T0309 Fixed-Bed Soil Biofilters—General
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0344 Geosafe Corporation, In Situ Vitrification
T0348 GHEA Associates, Soil Washing Technology
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0395 Idaho Research Foundation, Inc., and White Shield, Inc., Simplot Anaerobic Biological Remediation (SABRE)
T0416 Intech One Eighty, White-Rot Fungus
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0445 IT Corporation, Ozonation
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General
T0542 Mycotech Corporation, Fungal Bioremediation
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0546 Natural Attenuation—General
T0589 Pacific Northwest National Laboratory, Environmentally Benign Digestion Process (EBDP)
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0675 Roy F. Weston, Inc., Transportable Incineration Systems
T0756 Supercritical Water Oxidation—General
T0800 ThermoEnergy Corporation, NitRem
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0839 United States Army Environmental Center (USAEC), Hot-Gas Decontamination (HGD)
T0853 UV Technologies, Inc., UV-CATOX Technology
T0889 White-Rot Fungus—General

SINGLE-RING HETEROCYCLIC SULFUR COMPOUNDS

Single-Ring Heterocyclic Sulfur Compounds

T0200 Delphi Research, Inc., DETOX

Tetrachlorothiophene

T0200 Delphi Research, Inc., DETOX

SODIUM

T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0158 CH2M Hill, Phytoremediation-Based Systems
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0230 EET Corporation, Microwaste Waste Solidification
T0236 Electrokinetic Remediation—General
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0352 Golder Associates Corporation, Montan Wax Barrier
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0452 Joule-Heated Vitrification—General
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0540 MSE Technology Applications, Inc., Viscous Barrier Technology
T0565 Northern Watertek Corporation, Atomizing Freeze Crystallization—Snowfluent
T0596 Pecan-Based Granular Activated Carbon—General
T0607 Phytoremediation—General
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process

STRONTIUM

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0054 Arctech, Inc., Humasorb
T0058 Arctic Foundations, Inc., Cryogenic Barrier
T0059 Argonne National Laboratory, Advanced Integrated Solvent Extraction and Ion Exchange Systems
T0064 Argonne National Laboratory, Magnetically Assisted Chemical Separation (MACS)
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0118 Biosorption—General
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0236 Electrokinetic Remediation—General
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0279 Environmental Research and Development, Inc., Neutral Process for Heavy-Metals Removal
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0344 Geosafe Corporation, In Situ Vitrification
T0355 Granular Activated Carbon (GAC)—General

T0359 GTS Duratek, DuraMelter
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0404 In Situ Grouting—General
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0531 Mirage Systems, Inc., ChemChar Process
T0536 Molten Salt Oxidation—General
T0546 Natural Attenuation—General
T0587 Pacific Northwest National Laboratory, Permeable Clinoptilolite Barriers for Strontium
T0596 Pecan-Based Granular Activated Carbon—General
T0607 Phytoremediation—General
T0608 Phytoremediation: Hyperaccumulation—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0646 RedZone Robotics, Inc., Houdini
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0737 Spar Aerospace, Ltd., Light-Duty Utility Arm
T0798 Thermo Nuclean, Segmented Gate System (SGS)
T0800 ThermoEnergy Corporation, NitRem
T0819 U.S. Department of Energy Laboratories, Enhanced Sludge Washing
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0850 UOP, Ionsiv IE-911 Ion Exchange Resins
T0851 UOP, TIE-96 Ion Exchange Resins
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0887 Westinghouse Savannah River Corporation, Transportable Vitrification System
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process

SULFIDES, DISULFIDES

Dimethyl Disulfide

T0595 Peat/Compost Biofiltration—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

Dimethyl Sulfide

T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0355 Granular Activated Carbon (GAC)—General
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0595 Peat/Compost Biofiltration—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

Sulfides, Disulfides

T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0161 Chemical Oxidation—General
T0355 Granular Activated Carbon (GAC)—General
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads

T0458 Kenox Technology Corporation, Wet Air Oxidation
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0595 Peat/Compost Biofiltration—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

SULFUR, COMPOUNDS AND IONS

T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0251 Energy Biosystems Corporation, Biocatalytic Desulfurization
T0340 Geo-Microbial Technologies, Inc., Heteroatom Extraction Technology
T0355 Granular Activated Carbon (GAC)—General
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0617 PPC Biofilter, Biofiltration Systems
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General

SULFUR COMPOUNDS

Carbon Disulfide

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0127 Blast Fracturing—General
T0168 CleanSoil, Inc., CleanSoil Process
T0320 Funderburk & Associates, Solidification Process
T0355 Granular Activated Carbon (GAC)—General
T0372 Hi-Point Industries, Ltd., Oclansorb
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0899 Zenon Environmental Systems, Inc., ZenoGem
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Hydrogen Sulfide

T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0341 Geo-Microbial Technologies, Inc., Hydrogen Sulfide Removal
T0518 Met-Chem, Metal Kleen A
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0595 Peat/Compost Biofiltration—General
T0637 R.C. Costello and Associates, Inc., Actopentin Biomass Filter
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0855 Vapor-Phase Biofiltration—General

Sulfur Oxides

T0033 Ambient Engineering, Inc., BIOTON
T0090 Beco Engineering Company, Alka/Sorb
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0617 PPC Biofilter, Biofiltration Systems

SULFUR COMPOUNDS — OTHER SIGNIFICANT

Sulfur Hexafluoride

T0032 Alzeta Corporation, EDGE Thermal Processing Units

TECHNETIUM

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0060 Argonne National Laboratory, Aqueous Biphasic Extraction System
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0066 Argonne National Laboratory, Transuranium Extraction (TRUEX) Process
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0335 Geo-Con, Inc., Deep Soil Mixing
T0359 GTS Duratek, DuraMelter
T0373 Horizontal Drilling—General
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0509 Metal-Based Permeable Reactive Barriers—General
T0546 Natural Attenuation—General
T0586 Pacific Northwest National Laboratory, In Situ Redox Manipulation
T0601 Permeable Reactive Barriers (PRBs)—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process

TERTIARY ALCOHOLS

T0136 Calgon Carbon Oxidation Technologies, Rayox
T0161 Chemical Oxidation—General
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0546 Natural Attenuation—General

THALLIUM

T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0510 Metals Recovery, Inc., Metals Leaching

T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0789 Texilla Environmental, Inc., Synthetic Mineral Immobilization Technology (SMITE)

THIOLS

Methanethiol; Methyl Mercaptan

T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0161 Chemical Oxidation—General
T0355 Granular Activated Carbon (GAC)—General
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0595 Peat/Compost Biofiltration—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)

Thiols, Mercaptans

T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0309 Fixed-Bed Soil Biofilters—General
T0355 Granular Activated Carbon (GAC)—General
T0421 InterBio, Hydrobac
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0595 Peat/Compost Biofiltration—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0817 T-Thermal Company, Submerged Quench Incineration
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0855 Vapor-Phase Biofiltration—General

THIOLS, SULFIDES, AND DISULFIDES

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0161 Chemical Oxidation—General
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process

THORIUM

T0005 Active Environmental Technologies, Inc., TechXtract
T0060 Argonne National Laboratory, Aqueous Biphasic Extraction System
T0066 Argonne National Laboratory, Transuranium Extraction (TRUEX) Process
T0088 Battelle Pacific Northwest National Laboratory, Terra-VIT Vitrification Technology
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0232 Eichrom Industries, Inc., Diphonix

T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0247 Emerging Energy Marketing Firm, Inc., Low-Energy Transmutation
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0359 GTS Duratek, DuraMelter
T0404 In Situ Grouting—General
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0531 Mirage Systems, Inc., ChemChar Process
T0546 Natural Attenuation—General
T0582 Onyx Industrial Services, SOIL*EX
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0767 TechTran Environmental, Inc., RHM-1000 Process
T0798 Thermo Nuclean, Segmented Gate System (SGS)
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process

TIN

T0001 3M Company, 3M Empore Extraction Disk
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0162 Chemical Precipitation of Metals—General
T0232 Eichrom Industries, Inc., Diphonix
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0519 Met-Chem, Metal Kleen B (MCB)
T0692 SCC Environmental, Micro-Flo
T0763 Tallon, Inc., Virtokele

TITANIUM

T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0232 Eichrom Industries, Inc., Diphonix
T0359 GTS Duratek, DuraMelter
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0521 Met-Tech, Inc., Metal Separation by Liquid Ion Exchange
T0644 Recra Environmental, Inc., Alternating Current Electrocoagulation
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology

TOTAL PETROLEUM HYDROCARBONS (TPH)

T0001 3M Company, 3M Empore Extraction Disk
T0003 Abanaki Corporation, Active Belt Oil Skimmers
T0005 Active Environmental Technologies, Inc., TechXtract
T0009 Advanced Environmental Services, Inc., System 64MT Low-Temperature Thermal Desorption
T0011 Advanced Microbial Solutions, SuperBio
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0017 Advanced Soil Technologies, Thermal Desorption
T0019 AER Labs, Landtreat Process
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0030 Alternative Technologies for Waste, Inc., TerraSure
T0035 American Combustion, Inc., Pyretron Thermal Destruction System
T0036 American Soil Technologies, Inc., Bio-Spin
T0038 American Soil Technologies, Inc., SW-400 Soil Washing Unit
T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0043 Applied Membrane Technology (AMT), Inc., In Situ Oxygen Diffuser
T0044 Applied Natural Sciences, Inc., TreeMediation
T0047 Aqualogy BioRemedics Environmental, Quality NutriBac
T0048 Aqualogy BioRemedics Environmental, Quality PetroKlenz
T0049 Aqualogy BioRemedics, OptiSorb Encapsulate
T0050 Aquathermolysis—General
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0057 Arctech, Inc., Ozo-Detox
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0067 Ariel Industries, Inc., Ariel SST Low-Temperature Thermal Desorber
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0075 B & S Research, Inc., B&S Achieve-B&S Industrial
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0078 Barr Engineering Company, Co-Burning Technology
T0091 BenCHEM, Inc., Soil Washing Technology
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0093 Bio Solutions, Inc., Soil Slurry-Sequencing Batch Reactor
T0095 Bio-Electrics, Inc., Electrofrac Detoxification System
T0096 BioEnviroTech, Inc., BioPetro
T0098 BioGee International, Inc., BioGee HC
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0100 BioGenesis Enterprises, Inc., Soil Remediation and Cleaning Products
T0101 Bio-Genesis Technologies, Aerobic Biotreatment System (ABS)
T0102 Bio-Genesis Technologies, Bioremediation—GT-1000
T0104 Biogenie, Inc., Biogenie Biofiltration Process
T0105 Biogenie, Inc., Biogenie Biopile
T0106 Biological Activated Carbon—General
T0108 Biomin, Inc., Organoclay
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0113 Bioremediation Service, Inc., AquaPlant Biofilter System
T0114 Bioremediation Technology Services, Inc., BTS Method

T0115 Bioscience, Inc., BIOX Biotreater
T0116 Bioscience, Inc., Microcat
T0117 Bioslurping—General
T0119 Biosurfactants—General
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0139 Cancrete Environmental Solutions, Inc., Depocrete
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0143 Carson Environmental, Low-Temperature Oxidation
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0153 Certified Remediation Systems, Inc., CRS Process
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0155 CFX Corporation, CFX MiniFix
T0156 CH2M Hill and Reichhold, Inc., Jet Pump Recovery System
T0157 CH2M Hill, Waterflood Oil Recovery
T0158 CH2M Hill, Phytoremediation-Based Systems
T0159 Charbon Consultants, HCZyme
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0161 Chemical Oxidation—General
T0164 ChemPete, Inc., Bioremediation
T0165 Cherokee Environmental Group, The Bio-Solution
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0168 CleanSoil, Inc., CleanSoil Process
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0172 Combustion Process Manufacturing Corporation, CPMC Process
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0175 Composting—General
T0177 Conor Pacific, WINDsparge
T0178 Constructed Wetlands—General
T0181 Contamination Technologies, Inc., Low-Temperature Thermal Absorber (LTA)
T0182 ConTeck Environmental Services, Inc., Soil Roaster
T0186 Cosolvent Flushing—General
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0190 Cunningham-Davis Environmental (CDE Resources, Inc.), CDE Soil Recycling
T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0195 DAHL & Associates, Inc., ThermNet
T0196 Dames & Moore, Bioinfiltration
T0197 Dames and Moore, Two-Phase Vacuum Extraction

T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0200 Delphi Research, Inc., DETOX
T0201 Delta Cooling Towers, Inc., Aqua-Trim and Vanguard Air Strippers
T0202 Detox Industries, Inc., DETOX Process
T0203 Dissolved Air Flotation—General
T0204 Distillation—General
T0205 Diversified Remediation Controls, Inc., Turbostripper
T0206 Divesco, Inc., Soil Washing
T0208 Donald L. Geisel & Associates, Inc., HeatTrode Thermally Accelerated In Situ Bioremediation
T0211 DRL Environmental Services, Enco-Tec RS-30 Thermal Desorption
T0212 Dual-Phase Extraction—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0217 Dutch Pride Products, EcoPlus
T0219 E Products, Inc., Venturi Thermal Oxidizer
T0220 E.W.M.C. International, Inc., Emery Microwave Process
T0222 Earth Purification Engineering, Inc., Soil Cleanup System (SCS)
T0223 Earth Tech Bioremediation—Solid Phase
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0228 ECO-TEC, Inc., EnviroMech Gold Biocatalytic Contaminant Degradation
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized-Bed Reactor (GAC FBR) Process
T0233 Ejector Systems, Inc., VESTRIP
T0234 Ejector Systems, Inc., Stripperator
T0236 Electrokinetic Remediation—General
T0237 Electrokinetically Enhanced Bioremediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0241 Elf Atochem North America, Inc., INIPOL EAP-22 Microemulsion
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0252 Energy Products of Idaho, Fluidized-Bed Combustion
T0253 Energy Reclamation, Inc., Pyrolytic Waste Reclamation (PWR)
T0256 Ensite, Inc., SafeSoil
T0257 EnSolve Biosystems, Inc., EnCell Bioreactor
T0259 ENSR International Group, Biovault
T0260 ENSR International Group, Soil Cleaning Process
T0261 Enviro Products, Inc., PetroTrap
T0265 Envirogen, Inc., Electrokinetic Transport
T0267 Envirogen, Inc., Spartech
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE
T0270 EnviroLogical Engineering, Inc., Earthwise Formula 1
T0272 Environment Canada, Microwave-Assisted Process
T0274 Environmental Dynamics, Low-Temperature Plasma
T0275 Environmental Fuel Systems, Inc., Reclaim
T0276 Environmental Recycling, L.L.C., Asphalt-Stabilized Base/Engineered Backfill
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0278 Environmental Remediation International (EnRem), Ltd., Soil Remediation System (SRS)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0283 Environmental Solutions, Inc., CHEM-STA

T0287 Environmental Tune-Up, Inc., Apollo Oil–Water Separator
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0289 EnviroSep, Inc., Thick-Film Absorption (TFA)
T0290 Enviro-Soil Remediation, Inc., Thermal Stripping
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0296 EPG Companies, Inc., Oxidair Thermal Oxidizers
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0300 ETUS, Inc., Enhanced Bioremediation
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0303 Extraksol (vendor unknown)
T0305 Ferguson International, Inc., Petro-Belt and Dyna-Belt Hydrocarbon Skimmers
T0308 First Environment, Inc., FE ACTIVE
T0309 Fixed-Bed Soil Biofilters—General
T0310 Fluidized-Bed Thermal Oxidation—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0321 Fungi Perfecti, Mycova Mycoremediation and Mycofiltration
T0323 G.E.M., Inc., Chemical Treatment
T0329 General Atomics, Supercritical Water Oxidation
T0331 Genesis Eco Systems, Inc., Soil Treatment and Recycling
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0334 Geo-Con, Inc., Shallow Soil Mixing/Thermally Enhanced Vapor Extraction
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0340 Geo-Microbial Technologies, Inc., Heteroatom Extraction Technology
T0341 Geo-Microbial Technologies, Inc., Hydrogen Sulfide Removal
T0342 Geo-Microbial Technologies, Inc., Metals Release and Removal from Wastes
T0344 Geosafe Corporation, In Situ Vitrification
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0348 GHEA Associates, Soil Washing Technology
T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0351 Golder Applied Technologies, Inc., Hydraulic Fracturing/FracTool
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0356 Groundwater Recovery Systems, Inc., OXY 1
T0357 GSE Lining Technology, Inc., GSE CurtainWall Vertical Membrane Barrier System
T0358 GSE Lining Technology, Inc., GSE GundWall Vertical Membrane Barrier Systems
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0364 Harding ESE, Inc., Bioremediation—Landfarming Treatment
T0365 Harding ESE, Inc., Composting
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0369 Heaven from Earth, Inc., Organic Cleaners
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0374 Horizontal Technologies, Inc., Linear Containment Remediation System
T0375 Horizontal Technologies, Inc., Polywall Barrier System

T0376 Horner & Company, Max Bac
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process, In Situ
T0380 Hrubetz Environmental Services, Inc., HRUBOUT Process, Ex Situ
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0386 Hydrocarbon Environmental Recovery Systems, Bioremediation Response Advancement Technologies (BRAT)
T0387 Hydrocarbon Technologies, Inc., Recovered Oil Pyrolysis and Extraction (ROPE)
T0388 Hydrogen Peroxide In Situ Bioremediation—General
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0396 IEG Technologies Corporation, Coaxial Groundwater Ventilation (KGB)
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0399 IEG Technologies, Groundwater Circulation Wells (GZB)
T0400 IIT Research Institute, Radio Frequency Heating
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0402 Imperial Petroleum Recovery Corporation, MST 4000
T0405 In Situ Oil Skimmers—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0411 Institute of Gas Technology Fluid Extraction—Biological Degradation
T0419 Integrated Chemistries, Inc., Pentagone
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0421 InterBio, Hydrobac
T0422 InterBio, Petrobac
T0423 InterBio, Phenobac
T0425 International Environmental Technologies, Inc. (IET), Biodrain
T0427 International Landmark Environmental, Inc., Aminoplast Capillary Technology
T0433 IT Corporation, Biofast
T0434 IT Corporation, Biological Polishing Treatment
T0436 IT Corporation, Direct Application of Surfactants
T0437 IT Corporation, Engineered Bioremediation System
T0438 IT Corporation, Enhanced Natural Degradation (END)
T0439 IT Corporation, Fluid Injection with Vacuum Extraction
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0444 IT Corporation, Oxygen Microbubble In Situ Bioremediation
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0448 IT Corporation, Slurry-Phase Bioremediation—Pilot Scale
T0449 IT Corporation, Thermal Desorption
T0450 IT Corporation, Thermal Destruction Unit
T0452 Joule-Heated Vitrification—General
T0453 Kaiser-Hill Company, L.L.C., Supercritical Carbon Dioxide Extraction
T0454 KAL CON Environmental Services, Thermal Desorption
T0455 Kansas State University, Vibrorecovery
T0456 Keller Environmental, Inc., Bioinjection
T0457 KEMRON Environmental Services, Inc., Bioremediation—Soil and Groundwater
T0458 Kenox Technology Corporation, Wet Air Oxidation
T0459 King, Buck Technologies, Inc., HD CatOx System

T0460 King, Buck Technologies, Inc., MultiMode Combustion
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0468 KVA, C-Sparger System
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0476 Lehigh University, Ground Rubber as a Reactive Permeable Barrier Sorption Media
T0479 Limnofix, Inc., Limnofix In Situ Sediment Treatment (LIST)
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0489 M.L. Chartier, Inc., Therminator
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0495 Maple Engineering Services, Inc., Biopur
T0500 Maxymillian Technologies, Inc., Thermal Desorption System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0504 Medina Agricultural Products Company, Inc., Medina Bioremediation Products
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0511 Metals Removal Via Peat—General
T0516 Metcalf & Eddy, Inc., ORG-X
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0524 Microbes Research & Development, Inc., Uremel
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0526 Microbial Environmental Services, Inc. (MES), Bioremediation
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0530 MIOX Corporation, Miox System
T0532 Modified Natural Clays—General
T0536 Molten Salt Oxidation—General
T0541 MYCELX Technologies Corporation, MYCELX
T0542 Mycotech Corporation, Fungal Bioremediation
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0547 NEPCCO Environmental Systems, SoilPurge
T0548 NEPCCO Environmental Systems, SpargePurge
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0555 Niaski Environmental, Inc., Biopurge
T0556 Niaski Environmental, Inc., BioSparge System
T0558 NoChar, Inc., Petro-Bond
T0560 Normrock Industries, Inc., Amphibex Excavator
T0561 North American Drilling Technologies (NADT), Inc., EnviroZyme
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0566 NUCON International, Inc., Brayton Cycle
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)

T0573 O'Brien & Gere Engineers, Inc., Mechanical Volatilization Screening
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0576 Oil Waste Treatment Company, Terrazyme Phase Segregation
T0577 On-Site Technologies, Modular Interchangeable Treatment System (MITS)
T0578 OnSite Technology, L.L.C., Portable Indirect Thermal Desorption (ITD)
T0579 On-Site Thermal Services Division of Soil Restoration and Recycling, L.L.C., Low-Temperature Thermal Desorption Plant
T0580 Onsite*Ofsite, Inc., Petroleum Sludge Treatment
T0584 Osprey Biotechnics, Munox
T0591 Paragon Environmental Systems, Inc., Paragon SVE/Oxidizers
T0592 Passive Soil Vapor Extraction—General
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0595 Peat/Compost Biofiltration—General
T0597 Pedco, Inc., Rotary Cascading Bed Incineration
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0602 Pet-Con Soil Remediation, Inc., Thermal Desorption
T0603 Petro-Green, Inc., Petro-Green ADP-7
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0615 Polymer-Based Solidification/Stabilization—General
T0618 Praxair, Inc., MixFlo
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0621 Pressure Dewatering—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0626 Product Services Company, Oil Gator
T0628 PTC Enterprises, BioTreat System
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0631 Purus, Inc., Pulsed UV Irradiation
T0632 Pyrolysis—General
T0633 Pyrovac International, Inc., Pyrocycling Process
T0635 QED Environmental Systems, Inc., Ferret In-Well Separator
T0638 R.E. Wright Environmental, Inc., Steam-Enhanced Recovery
T0639 R.E. Wright Environmental, Inc., In Situ Bioremediation Treatment System
T0640 Radian International, L.L.C., Aeration Curtain
T0642 Recol Engineering, Ltd., RYMOX Technology
T0644 Recra Environmental, Inc., Alternating Current Electrocoagulation
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0648 Refranco Corporation, Sustained Shock Thermal Plasma
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0651 Remedial Concepts, L.L.C., DECHLOR #108 Solution
T0652 Remedial Concepts, L.L.C., STC Bison #308 and #508
T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0656 Remtech Engineers, Bubble Lance Low-Profile Diffused Air Stripper
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0662 RGF Environmental Group, CO3P System
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL

T0668 Rochem Environmental, Inc., Disc Tube
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0673 Rotating Biological Contactors—General
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0676 Rusmar, Inc., Long-Duration Foam
T0677 Rust Federal Services, Inc., VAC*TRAX Thermal Desorption
T0680 S.S. Papadopulos & Associates, Inc., DeNAPLs (Detergent Extraction of NAPLs)
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0684 Sanexen Environmental Services, Inc., Biolysis
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0688 Savannah River Ecology Laboratory, Selective Colloid Mobilization
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0692 SCC Environmental, Micro-Flo
T0693 SCC Environmental, Thermal-Phase Separation Unit
T0697 Science Remediation Services, Electro-Migration
T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0705 Separation and Recovery Systems, Inc., SAREX Chemical Fixation Process
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0707 Separation Dynamics, Inc., EXTRAN
T0708 Serengeti Products Company, Inc., Oil Snapper
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0718 Smith Technology Corporation, Two-Phase Vacuum Extraction
T0719 Soil/Sediment Washing—General
T0721 Soil Flushing—General
T0722 Soil Safe, Inc., Soil Recycling
T0724 Soil Technology, Inc., Soil Washing Treatability Study Unit
T0726 Solidification/Stabilization—General
T0727 Soliditech, Inc. Soliditech Solidification and Stabilization Process
T0731 Solvay Interox, Inc., ENVIROFirst Granules
T0732 Solvent Extraction—General
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0735 Sound Remedial Technologies, Inc., Hot Air Vapor Extraction (HAVE)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0739 SRE, Inc., Solv-ex
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0750 Stevens Institute of Technology, Trench Bio-Sparge

T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0753 Summit Research Corporation, Supercritical Water Oxidation
T0754 SuperAll Products, Inc., SuperAll #38
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0759 Surfactants—General
T0760 Surtek, Inc., Surfactant Remediation
T0761 Sybron Chemicals, Inc., ABR (Augmented Bioreclamation) Microbial Blends
T0763 Tallon, Inc., Virtokele
T0764 Tarmac Environmental Company, Inc., Thermal Desorption
T0765 Technology Scientific, Ltd., Flow Consecutor Technology (FCT)
T0768 Tekno Associates, Biolift
T0769 Terra Resources, Ltd., Terra Wash Soil Washing
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0780 Terra Vac, Soil Heating
T0782 Terra-Kleen Response Group, Inc., Solvent Extraction Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0792 The Westford Chemical Corporation BioSolv
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0799 ThermoChem, Inc., PulseEnhanced Steam Reformer
T0801 Thermoplastic Stabilization/Solidification—General
T0802 ThermoRetec, Microbial Fence
T0803 ThermoRetec, Prepared Bed Bioremediation
T0804 ThermoRetec, Slurry-Phase Bioremediation
T0805 ThermoRetec, Thermatek Thermal Desorption
T0806 Thermotech Systems Corporation, Soil Remediation Unit
T0809 Toronto Harbour Commissioners, Soil Recycle Treatment Train
T0810 Toxic Environmental Control Systems, Inc., Electrode-Assisted Soil Washing
T0811 TPS Technologies, Inc., Thermal Desorption
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0813 Trigon Group, L.L.C., Soil Washing
T0815 Trigon Group, L.L.C., ARCHON In Situ Mixer
T0816 TRW Systems & Information Technology Group, Microbial Enhanced Recovery
T0818 TVIES, Inc., Soil Washing
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0829 U.S. Microbics, Inc., Bio-Raptor
T0831 U.S. Waste Thermal Processing, Model 100 Mobile Thermal Processor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0838 United Retek Corporation, Asphalt Emulsion Stabilization

T0846 University of Massachusetts, Oleophilic Suction Lysimetry
T0847 University of New South Wales, Upflow Washing
T0848 University of Southern California, Hybrid Microfiltration-Bioactive Carbon Process
T0852 US EPA Risk Reduction Engineering Laboratory, Mobile Volume Reduction Unit (VRU)
T0855 Vapor-Phase Biofiltration—General
T0856 Vecor Industries, Inc., Apollo Greenzyme
T0857 Vendor Unknown, Calochroma Soil Washing
T0863 W.E.S., Inc., Microb-Sparging
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0869 Waste Microbes International (WMI), Inc., WMI-2000
T0870 Waste Stream Technology, Inc., Bioremediation
T0871 WASTECH, Inc., Solidification and Stabilization
T0873 Water Equipment Services, Inc., Environmental Division Vacu-Point
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0878 Weiss Associates, Acoustic-Enhanced Remediation
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0888 Wet Oxidation—General
T0889 White-Rot Fungus—General
T0890 WIK Associates, Inc., Bugs+Plus
T0891 Williams Environmental, RamSorb-1
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0893 WRS Infrastructure & Environmental, Inc., Thermal Desorption Unit
T0894 Xerox Corporation, Two-Phase Extraction System
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat
T0899 Zenon Environmental Systems, Inc., ZenoGem
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System
T0901 Zeros USA, Inc., Zero-Emission Energy Recycling System (ZEROS)

TUNGSTEN

T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0280 Environmental Research and Development, Inc., Ice Electrode

UNSATURATED ALKYL HALIDES

Aldrin

T0001 3M Company, 3M Empore Extraction Disk
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0124 BioTrol, Inc., Soil Washing Technology
T0138 Calgon Carbon Corporation, Perox-Pure
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0323 G.E.M., Inc., Chemical Treatment
T0344 Geosafe Corporation, In Situ Vitrification
T0400 IIT Research Institute, Radio Frequency Heating
T0452 Joule-Heated Vitrification—General
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)

T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0755 Supercritical Carbon Dioxide Extraction—General
T0794 Thermal Desorption—General
T0817 T-Thermal Company, Submerged Quench Incineration
T0889 White-Rot Fungus—General

Chlordane; Octachlorohexahydromethanoindene

T0001 3M Company, 3M Empore Extraction Disk
T0056 Arctech, Inc., Light-Activated Reduction of Chemicals (LARC)
T0124 BioTrol, Inc., Soil Washing Technology
T0138 Calgon Carbon Corporation, Perox-Pure
T0175 Composting—General
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0416 Intech One Eighty, White-Rot Fungus
T0432 IT Corporation, Below-Grade Bioremediation
T0452 Joule-Heated Vitrification—General
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0536 Molten Salt Oxidation—General
T0607 Phytoremediation—General
T0613 Plasma Vitrification—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0755 Supercritical Carbon Dioxide Extraction—General
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0817 T-Thermal Company, Submerged Quench Incineration
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0889 White-Rot Fungus—General

Dichloroethene, 1,1

T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit

T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0127 Blast Fracturing—General
T0138 Calgon Carbon Corporation, Perox-Pure
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0161 Chemical Oxidation—General
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0212 Dual-Phase Extraction—General
T0225 Ecology Technologies International, Inc., FyreZyme
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0258 ENSR International Group, Anaerobic Biotransformation with Steam Injection
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0335 Geo-Con, Inc., Deep Soil Mixing
T0353 Golder Associates Corporation, Vertically Oriented Hydraulic Fracture Placed Iron Reactor Walls
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0374 Horizontal Technologies, Inc., Linear Containment Remediation System
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0494 ManTech Environmental Corporation, CleanOX Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0546 Natural Attenuation—General
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0631 Purus, Inc., Pulsed UV Irradiation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0771 Terra Vac, DNAPL Vaporization
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0778 Terra Vac, Inc., Sparge VAC
T0780 Terra Vac, Soil Heating
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Dichloroethene, 1,2; DCE

T0005 Active Environmental Technologies, Inc., TechXtract
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System

T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0032 Alzeta Corporation, EDGE Thermal Processing Units
T0044 Applied Natural Sciences, Inc., TreeMediation
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0125 BioTrol, Inc., Methanotropic Bioreactor System
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0178 Constructed Wetlands—General
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0212 Dual-Phase Extraction—General
T0225 Ecology Technologies International, Inc., FyreZyme
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0258 ENSR International Group, Anaerobic Biotransformation with Steam Injection
T0259 ENSR International Group, Biovault
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0312 FOREMOST Solutions, Inc., IronNet and Iron Curtain
T0320 Funderburk & Associates, Solidification Process
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0334 Geo-Con, Inc., Shallow Soil Mixing/Thermally Enhanced Vapor Extraction
T0348 GHEA Associates, Soil Washing Technology
T0351 Golder Applied Technologies, Inc., Hydraulic Fracturing/FracTool
T0353 Golder Associates Corporation, Vertically Oriented Hydraulic Fracture Placed Iron Reactor Walls
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0445 IT Corporation, Ozonation
T0459 King, Buck Technologies, Inc., HD CatOx System
T0467 KSE, Inc., AIR-II Process

T0468 KVA, C-Sparger System
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0494 ManTech Environmental Corporation, CleanOX Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0509 Metal-Based Permeable Reactive Barriers—General
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0533 Molasses Treatment for Bioremediation—General
T0546 Natural Attenuation—General
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0592 Passive Soil Vapor Extraction—General
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0639 R.E. Wright Environmental, Inc., In Situ Bioremediation Treatment System
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0728 Solox, Hybrid Solar/Electric Ultraviolet Oxidation System
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0756 Supercritical Water Oxidation—General
T0771 Terra Vac, DNAPL Vaporization
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0778 Terra Vac, Inc., Sparge VAC
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0825 U.S. Filter, Ultrox Peroxone Oxidation
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0894 Xerox Corporation, Two-Phase Extraction System
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Heptachlor

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0323 G.E.M., Inc., Chemical Treatment
T0344 Geosafe Corporation, In Situ Vitrification
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0432 IT Corporation, Below-Grade Bioremediation
T0445 IT Corporation, Ozonation
T0452 Joule-Heated Vitrification—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0755 Supercritical Carbon Dioxide Extraction—General
T0794 Thermal Desorption—General
T0889 White-Rot Fungus—General

Hexachlorobutadiene

T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0355 Granular Activated Carbon (GAC)—General
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0449 IT Corporation, Thermal Desorption
T0450 IT Corporation, Thermal Destruction Unit
T0487 Louisiana State University, Colloidal Gas Aphron
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0546 Natural Attenuation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0794 Thermal Desorption—General

Hexachlorocyclopentadiene

T0329 General Atomics, Supercritical Water Oxidation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0756 Supercritical Water Oxidation—General

Tetrachloroethene; Perchloroethylene; PCE

T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General

T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0044 Applied Natural Sciences, Inc., TreeMediation
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0054 Arctech, Inc., Humasorb
T0063 Argonne National Laboratory, In-Well Sonication
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0084 Battelle Pacific Northwest Laboratory, Gas-Phase Corona Reactor
T0087 Battelle Pacific Northwest National Laboratory, Liquid Corona
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0108 Biomin, Inc., Organoclay
T0114 Bioremediation Technology Services, Inc., BTS Method
T0127 Blast Fracturing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0186 Cosolvent Flushing—General
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0195 DAHL & Associates, Inc., ThermNet
T0197 Dames and Moore, Two-Phase Vacuum Extraction
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0212 Dual-Phase Extraction—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0225 Ecology Technologies International, Inc., FyreZyme
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0259 ENSR International Group, Biovault
T0267 Envirogen, Inc., Spartech
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0292 EnviroWall, Inc., EnviroWall Barrier

T0308 First Environment, Inc., FE ACTIVE
T0310 Fluidized-Bed Thermal Oxidation—General
T0312 FOREMOST Solutions, Inc., IronNet and Iron Curtain
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0335 Geo-Con, Inc., Deep Soil Mixing
T0344 Geosafe Corporation, In Situ Vitrification
T0351 Golder Applied Technologies, Inc., Hydraulic Fracturing/FracTool
T0353 Golder Associates Corporation, Vertically Oriented Hydraulic Fracture Placed Iron Reactor Walls
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0397 IEG Technologies Corporation, Soil Air Circulation (BLK)
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0400 IIT Research Institute, Radio Frequency Heating
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0445 IT Corporation, Ozonation
T0449 IT Corporation, Thermal Desorption
T0450 IT Corporation, Thermal Destruction Unit
T0454 KAL CON Environmental Services, Thermal Desorption
T0459 King, Buck Technologies, Inc., HD CatOx System
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0501 MBI International, Anaerobic PCB Dechlorinating Granular Consortia
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products

T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0529 Millgard Corporation, MecTool Remediation System
T0530 MIOX Corporation, Miox System
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0546 Natural Attenuation—General
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0568 Oak Hill Company, Ltd., In Situ Saturated Zone Treatment
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0584 Osprey, Biotechnics Munox
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0592 Passive Soil Vapor Extraction—General
T0595 Peat/Compost Biofiltration—General
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0631 Purus, Inc., Pulsed UV Irradiation
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0652 Remedial Concepts, L.L.C., STC Bison #308 and #508
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0695 Science & Engineering Associates, Inc., Barometrically Enhanced Remediation Technology (BERT)
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0728 Solox, Hybrid Solar/Electric Ultraviolet Oxidation System
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0756 Supercritical Water Oxidation—General

T0771 Terra Vac, DNAPL Vaporization
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0780 Terra Vac, Soil Heating
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0820 U.S. Environmental Protection Agency, Reductive Anaerobic Biological In Situ Treatment (RABIT)
T0823 U.S. Filter Corporation, PO*WW*ER Wastewater Treatment System
T0825 U.S. Filter, Ultrox Peroxone Oxidation
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0841 University of Akron, Sonochemical Destruction
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0884 Westinghouse Savannah River Company, In Situ Bioremediation of Chlorinated Solvents with Natural Gas
T0885 Westinghouse Savannah River Company, In Situ Air Stripping
T0894 Xerox Corporation, Two-Phase Extraction System
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Toxaphene; Chlorinated Camphor

T0001 3M Company, 3M Empore Extraction Disk
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0114 Bioremediation Technology Services, Inc., BTS Method
T0135 Calgon Carbon Corporation, Activated Carbon
T0320 Funderburk & Associates, Solidification Process
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0389 HyroScience, Inc., Hydrolytic Terrestrial Dissipation
T0416 Intech One Eighty, White-Rot Fungus
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0509 Metal-Based Permeable Reactive Barriers—General
T0607 Phytoremediation—General
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)

T0755 Supercritical Carbon Dioxide Extraction—General
T0794 Thermal Desorption—General
T0889 White-Rot Fungus—General

Trichloroethene; Trichloroethylene; TCE

T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0032 Alzeta Corporation, EDGE Thermal Processing Units
T0044 Applied Natural Sciences, Inc., TreeMediation
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0054 Arctech, Inc., Humasorb
T0063 Argonne National Laboratory, In-Well Sonication
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0084 Battelle Pacific Northwest Laboratory, Gas-Phase Corona Reactor
T0087 Battelle Pacific Northwest National Laboratory, Liquid Corona
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0108 Biomin, Inc., Organoclay
T0111 BioRemedial Technologies, Inc., Compound C
T0114 Bioremediation Technology Services, Inc., BTS Method
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0125 BioTrol, Inc., Methanotropic Bioreactor System
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0146 Catalytic Combustion Corporation, SRCO and HD-SRCO
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0158 CH2M Hill, Phytoremediation-Based Systems
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0164 ChemPete, Inc., Bioremediation
T0168 CleanSoil Inc., CleanSoil Process
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0178 Constructed Wetlands—General
T0186 Cosolvent Flushing—General

T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0195 DAHL & Associates, Inc., ThermNet
T0197 Dames and Moore, Two-Phase Vacuum Extraction
T0200 Delphi Research, Inc., DETOX
T0212 Dual Phase Extraction—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0236 Electrokinetic Remediation—General
T0237 Electrokinetically Enhanced Bioremediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0258 ENSR International Group, Anaerobic Biotransformation with Steam Injection
T0259 ENSR International Group, Biovault
T0263 Envirogen, Adhesive-Deficient Bacteria
T0264 Envirogen, TCE-Degrading Bacteria
T0265 Envirogen, Inc., Electrokinetic Transport
T0267 Envirogen, Inc., Spartech
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0275 Environmental Fuel Systems, Inc., Reclaim
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0289 EnviroSep, Inc., Thick-Film Absorption (TFA)
T0292 EnviroWall, Inc., EnviroWall Barrier
T0295 EOD Technology, Inc., Biotechnical Processing of Explosives
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0308 First Environment, Inc., FE ACTIVE
T0309 Fixed-Bed Soil Biofilters—General
T0310 Fluidized-Bed Thermal Oxidation—General
T0312 FOREMOST Solutions, Inc., IronNet and Iron Curtain
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0329 General Atomics, Supercritical Water Oxidation
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0334 Geo-Con Inc., Shallow Soil Mixing/Thermally Enhanced Vapor Extraction
T0335 Geo-Con, Inc., Deep Soil Mixing
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0344 Geosafe Corporation, In Situ Vitrification
T0348 GHEA Associates, Soil Washing Technology
T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0351 Golder Applied Technologies, Inc., Hydraulic Fracturing/FracTool
T0353 Golder Associates Corporation, Vertically Oriented Hydraulic Fracture Placed Iron Reactor Walls
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation

T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0374 Horizontal Technologies, Inc., Linear Containment Remediation System
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0397 IEG Technologies Corporation, Soil Air Circulation (BLK)
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0400 IIT Research Institute, Radio Frequency Heating
T0404 In Situ Grouting—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0449 IT Corporation, Thermal Desorption
T0459 King, Buck Technologies, Inc., HD CatOx System
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0475 Lawrence Livermore National Laboratory, In Situ Microbial Filters
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0494 ManTech Environmental Corporation, CleanOX Process
T0497 Massachusetts Institute of Technology, Tunable Hybrid Plasma
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0501 MBI International, Anaerobic PCB Dechlorinating Granular Consortia
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0520 Methanotrophic Biofilters—General
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0529 Millgard Corporation, MecTool Remediation System
T0530 MIOX Corporation, Miox System
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General
T0537 Monsanto Company, Lasagna
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0546 Natural Attenuation—General
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0555 Niaski Environmental, Inc., Biopurge

T0556 Niaski Environmental, Inc., BioSparge System
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0568 Oak Hill Company, Ltd., In Situ Saturated Zone Treatment
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0582 Onyx Industrial Services, SOIL*EX
T0584 Osprey Biotechnics, Munox
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0586 Pacific Northwest National Laboratory, In Situ Redox Manipulation
T0592 Passive Soil Vapor Extraction—General
T0595 Peat/Compost Biofiltration—General
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0628 PTC Enterprises, BioTreat System
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0631 Purus, Inc., Pulsed UV Irradiation
T0639 R.E. Wright Environmental, Inc., In Situ Bioremediation Treatment System
T0640 Radian International, L.L.C., Aeration Curtain
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0663 Rizzo Associates, Inc., Chlorinated Solvent Cleanup (Butane Biostimulation Technology)
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0672 Rohm and Haas Company, Ambersorb 600
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0676 Rusmar, Inc., Long-Duration Foam
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0694 Schonberg Radiation Corporation, Toxic Remediation Using Radiation
T0695 Science & Engineering Associates, Inc., Barometrically Enhanced Remediation Technology (BERT)
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0728 Solox, Hybrid Solar/Electric Ultraviolet Oxidation System
T0735 Sound Remedial Technologies, Inc., Hot Air Vapor Extraction (HAVE)
T0738 SpinTek Systems, SpinTek

T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0756 Supercritical Water Oxidation—General
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0771 Terra Vac, DNAPL Vaporization
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0780 Terra Vac, Soil Heating
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0788 Texas A&M University, Low-Pressure Surface Wave Plasma Reactor
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0803 ThermoRetec, Prepared Bed Bioremediation
T0807 Thorneco, Inc., Enzyme-Activated Cellulose Technology
T0820 U.S. Environmental Protection Agency, Reductive Anaerobic Biological In Situ Treatment (RABIT)
T0825 U.S. Filter, Ultrox Peroxone Oxidation
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0835 Umpqua Research Company, Low-Temperature Aqueous Phase Catalytic Oxidation
T0841 University of Akron, Sonochemical Destruction
T0844 University of Connecticut, Contaminant Absorption and Recovery
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0857 Vendor Unknown, Calochroma Soil Washing
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0871 WASTECH, Inc., Solidification and Stabilization
T0884 Westinghouse Savannah River Company, In Situ Bioremediation of Chlorinated Solvents with Natural Gas
T0885 Westinghouse Savannah River Company, In Situ Air Stripping
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0889 White-Rot Fungus—General
T0894 Xerox Corporation, Two-Phase Extraction System
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II

T0898 Zapit Technology, Inc., Zapit Processing Unit
T0899 Zenon Environmental Systems, Inc., ZenoGem
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Unsaturated Alkyl Halides

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0020 Aeration Basins—General
T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0032 Alzeta Corporation, EDGE Thermal Processing Units
T0044 Applied Natural Sciences, Inc., TreeMediation
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0054 Arctech, Inc., Humasorb
T0056 Arctech, Inc., Light-Activated Reduction of Chemicals (LARC)
T0063 Argonne National Laboratory, In-Well Sonication
T0065 Argonne National Laboratory, Remediation Using Foam Technology
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0084 Battelle Pacific Northwest Laboratory, Gas-Phase Corona Reactor
T0087 Battelle Pacific Northwest National Laboratory, Liquid Corona
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0108 Biomin, Inc., Organoclay
T0111 BioRemedial Technologies, Inc., Compound C
T0114 Bioremediation Technology Services, Inc., BTS Method
T0121 BioSystems Technology, Inc., Chlorinated Solvent Remediation (CSR)
T0124 BioTrol, Inc., Soil Washing Technology
T0125 BioTrol, Inc., Methanotropic Bioreactor System
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0129 Bogart Environmental Services, Inc., MiKIE
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0146 Catalytic Combustion Corporation, SRCO and HD-SRCO
T0147 Catalytic Oxidation—General

T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0149 Cement-Based Stabilization/Solidification—General
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0158 CH2M Hill, Phytoremediation-Based Systems
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0164 ChemPete, Inc., Bioremediation
T0168 CleanSoil Inc., CleanSoil Process
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0175 Composting—General
T0178 Constructed Wetlands—General
T0186 Cosolvent Flushing—General
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0195 DAHL & Associates, Inc., ThermNet
T0197 Dames and Moore, Two-Phase Vacuum Extraction
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0200 Delphi Research, Inc., DETOX
T0212 Dual-Phase Extraction—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0236 Electrokinetic Remediation—General
T0237 Electrokinetically Enhanced Bioremediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0258 ENSR International Group, Anaerobic Biotransformation with Steam Injection
T0259 ENSR International Group, Biovault
T0263 Envirogen, Adhesive-Deficient Bacteria
T0264 Envirogen, TCE-Degrading Bacteria
T0265 Envirogen, Inc., Electrokinetic Transport
T0267 Envirogen, Inc., Spartech
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0275 Environmental Fuel Systems, Inc., Reclaim
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0289 EnviroSep, Inc., Thick-Film Absorption (TFA)
T0292 EnviroWall, Inc., EnviroWall Barrier
T0295 EOD Technology, Inc., Biotechnical Processing of Explosives
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0308 First Environment, Inc., FE ACTIVE
T0309 Fixed-Bed Soil Biofilters—General
T0310 Fluidized-Bed Thermal Oxidation—General
T0312 FOREMOST Solutions, Inc., IronNet and Iron Curtain
T0318 FRX, Inc., Hydraulic Fracturing
T0320 Funderburk & Associates, Solidification Process
T0323 G.E.M., Inc., Chemical Treatment

T0329 General Atomics, Supercritical Water Oxidation
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0334 Geo-Con Inc., Shallow Soil Mixing/Thermally Enhanced Vapor Extraction
T0335 Geo-Con, Inc., Deep Soil Mixing
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0348 GHEA Associates, Soil Washing Technology
T0349 Global Remediation Technologies, Inc., Pressurized Fluidized Bioreactor (PFBR)
T0351 Golder Applied Technologies, Inc., Hydraulic Fracturing/FracTool
T0353 Golder Associates Corporation, Vertically Oriented Hydraulic Fracture Placed Iron Reactor Walls
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0373 Horizontal Drilling—General
T0374 Horizontal Technologies, Inc., Linear Containment Remediation System
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0389 HyroScience, Inc., Hydrolytic Terrestrial Dissipation
T0391 ICI Explosives Environmental Company, ICI Explosives Incineration Process
T0397 IEG Technologies Corporation, Soil Air Circulation (BLK)
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0400 IIT Research Institute, Radio Frequency Heating
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0404 In Situ Grouting—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0416 Intech One Eighty, White-Rot Fungus
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0432 IT Corporation, Below-Grade Bioremediation
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0445 IT Corporation, Ozonation
T0449 IT Corporation, Thermal Desorption
T0450 IT Corporation, Thermal Destruction Unit
T0452 Joule-Heated Vitrification—General
T0454 KAL CON Environmental Services, Thermal Desorption
T0459 King, Buck Technologies, Inc., HD CatOx System
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation

T0475 Lawrence Livermore National Laboratory, In Situ Microbial Filters
T0487 Louisiana State University, Colloidal Gas Aphron
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process
T0497 Massachusetts Institute of Technology, Tunable Hybrid Plasma
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0501 MBI International, Anaerobic PCB Dechlorinating Granular Consortia
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0520 Methanotrophic Biofilters—General
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0530 MIOX Corporation, Miox System
T0533 Molasses Treatment for Bioremediation—General
T0536 Molten Salt Oxidation—General
T0537 Monsanto Company, Lasagna
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0546 Natural Attenuation—General
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0554 New Mexico Institute of Mining and Technology, Surfactant-Modified Zeolite
T0555 Niaski Environmental, Inc., Biopurge
T0556 Niaski Environmental, Inc., BioSparge System
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0568 Oak Hill Company, Ltd., In Situ Saturated Zone Treatment
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0573 O'Brien & Gere Engineers, Inc., Mechanical Volatilization Screening
T0574 Ocean Arks International and Living Technologies, Living Machine/Restorer
T0582 Onyx Industrial Services, SOIL*EX
T0584 Osprey Biotechnics, Munox
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0586 Pacific Northwest National Laboratory, In Situ Redox Manipulation
T0592 Passive Soil Vapor Extraction—General
T0595 Peat/Compost Biofiltration—General
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0613 Plasma Vitrification—General
T0616 Pozzolanic Solidification/Stabilization—General
T0618 Praxair, Inc., MixFlo
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0628 PTC Enterprises, BioTreat System

T0629 Pulse Sciences, Inc., X-Ray Treatment
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0631 Purus, Inc., Pulsed UV Irradiation
T0639 R.E. Wright Environmental, Inc., In Situ Bioremediation Treatment System
T0640 Radian International, L.L.C., Aeration Curtain
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0652 Remedial Concepts, L.L.C., STC Bison #308 and #508
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0663 Rizzo Associates, Inc., Chlorinated Solvent Cleanup (Butane Biostimulation Technology)
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0672 Rohm and Haas Company, Ambersorb 600
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0676 Rusmar, Inc., Long-Duration Foam
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0689 SBP Technologies, Inc., Membrane Filtration
T0690 SBP Technologies, Inc., Slurry-Phase Bioremediation
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0694 Schonberg Radiation Corporation, Toxic Remediation Using Radiation
T0695 Science & Engineering Associates, Inc., Barometrically Enhanced Remediation Technology (BERT)
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0726 Solidification/Stabilization—General
T0728 Solox, Hybrid Solar/Electric Ultraviolet Oxidation System
T0735 Sound Remedial Technologies, Inc., Hot Air Vapor Extraction (HAVE)
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0738 SpinTek Systems, SpinTek
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0771 Terra Vac, DNAPL Vaporization
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0778 Terra Vac, Inc., Sparge VAC

T0779 Terra Vac, Inc., Vacuum Extraction
T0780 Terra Vac, Soil Heating
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0788 Texas A&M University, Low-Pressure Surface Wave Plasma Reactor
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0803 ThermoRetec, Prepared Bed Bioremediation
T0807 Thorneco, Inc., Enzyme-Activated Cellulose Technology
T0817 T-Thermal Company, Submerged Quench Incineration
T0820 U.S. Environmental Protection Agency, Reductive Anaerobic Biological In Situ Treatment (RABIT)
T0823 U.S. Filter Corporation, PO*WW*ER Wastewater Treatment System
T0825 U.S. Filter, Ultrox Peroxone Oxidation
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0835 Umpqua Research Company, Low-Temperature Aqueous-Phase Catalytic Oxidation
T0841 University of Akron, Sonochemical Destruction
T0844 University of Connecticut, Contaminant Absorption and Recovery
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0857 Vendor Unknown, Calochroma Soil Washing
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0871 WASTECH, Inc., Solidification and Stabilization
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0884 Westinghouse Savannah River Company, In Situ Bioremediation of Chlorinated Solvents with Natural Gas
T0885 Westinghouse Savannah River Company, In Situ Air Stripping
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0889 White-Rot Fungus—General
T0894 Xerox Corporation, Two-Phase Extraction System
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0899 Zenon Environmental Systems, Inc., ZenoGem
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

Vinyl Chloride

T0005 Active Environmental Technologies, Inc., TechXtract
T0011 Advanced Microbial Solutions, SuperBio
T0020 Aeration Basins—General
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)

T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0125 BioTrol, Inc., Methanotropic Bioreactor System
T0127 Blast Fracturing—General
T0129 Bogart Environmental Services, Inc., MiKIE
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0138 Calgon Carbon Corporation, Perox-Pure
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0149 Cement-Based Stabilization/Solidification—General
T0161 Chemical Oxidation—General
T0168 CleanSoil, Inc., CleanSoil Process
T0178 Constructed Wetlands—General
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0258 ENSR International Group, Anaerobic Biotransformation with Steam Injection
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0275 Environmental Fuel Systems, Inc., Reclaim
T0277 Environmental Remediation Consultants, Inc., Biointegration
T0312 FOREMOST Solutions, Inc., IronNet and Iron Curtain
T0320 Funderburk & Associates, Solidification Process
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0353 Golder Associates Corporation, Vertically Oriented Hydraulic Fracture Placed Iron Reactor Walls
T0355 Granular Activated Carbon (GAC)—General
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation
T0372 Hi-Point Industries, Ltd., Oclansorb
T0374 Horizontal Technologies, Inc., Linear Containment Remediation System
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0445 IT Corporation, Ozonation
T0459 King, Buck Technologies, Inc., HD CatOx System
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0487 Louisiana State University, Colloidal Gas Aphron
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0494 ManTech Environmental Corporation, CleanOX Process
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System

T0509 Metal-Based Permeable Reactive Barriers—General
T0533 Molasses Treatment for Bioremediation—General
T0546 Natural Attenuation—General
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0573 O'Brien & Gere Engineers, Inc., Mechanical Volatilization Screening
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0592 Passive Soil Vapor Extraction—General
T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0616 Pozzolanic Solidification/Stabilization—General
T0618 Praxair, Inc., MixFlo
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0631 Purus, Inc., Pulsed UV Irradiation
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0676 Rusmar, Inc., Long-Duration Foam
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0726 Solidification/Stabilization—General
T0771 Terra Vac, DNAPL Vaporization
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0825 U.S. Filter, Ultrox Peroxone Oxidation
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0899 Zenon Environmental Systems, Inc., ZenoGem
T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System

URANIUM

T0005 Active Environmental Technologies, Inc., TechXtract
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0013 Advanced Recovery Systems, Inc., Deact Soil Washing
T0014 Advanced Recovery Systems, Inc., DeCaF
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0054 Arctech, Inc., Humasorb
T0058 Arctic Foundations, Inc., Cryogenic Barrier
T0059 Argonne National Laboratory, Advanced Integrated Solvent Extraction and Ion Exchange Systems
T0060 Argonne National Laboratory, Aqueous Biphasic Extraction System
T0062 Argonne National Laboratory, Ceramicrete Stabilization Technology
T0066 Argonne National Laboratory, Transuranium Extraction (TRUEX) Process
T0072 Atomic Energy of Canada, Ltd. (AECL), CHEMIC Technology
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0077 B & W Services, Inc., EcoSafe Soil Washing

T0088 Battelle Pacific Northwest National Laboratory, Terra-VIT Vitrification Technology
T0118 Biosorption—General
T0127 Blast Fracturing—General
T0131 Brice Environmental Services Corporation (BESCORP), Soil Washing System (BSWS)
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0158 CH2M Hill, Phytoremediation-Based Systems
T0170 Clyde Engineering Service, Metals Removal
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0214 DuPont/Oberlin, Microfiltration Technology
T0218 Dynaphore, Inc., Forager Sponge Technology
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0232 Eichrom Industries, Inc., Diphonix
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0240 Electro-Pyrolysis, Inc., DC Graphite Arc Furnace
T0262 Envirocare of Utah, Inc., Polyethylene Encapsulation
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0280 Environmental Research and Development, Inc., Ice Electrode
T0298 Eriksson Sediment Systems, Inc., Eriksson System
T0304 F2 Associates, Inc., Laser Ablation
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0335 Geo-Con, Inc., Deep Soil Mixing
T0343 Georgia Institute of Technology Construction Research Center, In Situ Plasma Vitrification
T0344 Geosafe Corporation, In Situ Vitrification
T0359 GTS Duratek, DuraMelter
T0382 Humboldt State University, Chitosan Derivative
T0404 In Situ Grouting—General
T0428 International Landmark Environmental, Inc., Diatomite
T0430 ISOTRON Corporation, Electrokinetic Decontamination Process
T0443 IT Corporation, In Situ Geochemical Fixation
T0452 Joule-Heated Vitrification—General
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0481 Lockheed Martin Corporation, Acid Extraction
T0485 Los Alamos National Laboratory, High-Gradient Magnetic Separation for Radioactive Soils and Process Wastes
T0486 Los Alamos National Laboratory, Uranium Heap Leaching Technology
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0509 Metal-Based Permeable Reactive Barriers—General
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0531 Mirage Systems, Inc., ChemChar Process
T0535 Molten Metal Technology, Inc., Quantum Catalytic Extraction Process (Q-CEP)
T0536 Molten Salt Oxidation—General
T0538 Montana Tech of the University of Montana, Campbell Centrifugal Jig

T0546 Natural Attenuation—General
T0569 Oak Ridge National Laboratory, Glass Material Oxidation and Dissolution System
T0582 Onyx Industrial Services, SOIL*EX
T0583 Oregon State University, Chitosan Beads
T0586 Pacific Northwest National Laboratory, In Situ Redox Manipulation
T0588 Pacific Northwest National Laboratory, Self-Assembled Mesoporous Support (SAMMS) Technology
T0600 Perma-Fix Environmental Services, Inc., Perma-Fix Process
T0601 Permeable Reactive Barriers (PRBs)—General
T0607 Phytoremediation—General
T0608 Phytoremediation: Hyperaccumulation–General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0624 Proactive Applied Solutions Corporation, LEADX
T0658 Resource Management and Recovery, AlgaSORB
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0678 S.G. Frantz Company, Inc., Magnetic Barrier Separation
T0682 Sandia National Laboratories, Electrokinetic Remediation
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc., MAECTITE Chemical Treatment Process
T0719 Soil/Sediment Washing—General
T0743 Starmet Corporation, DUCRETE Concrete
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0766 Technology Visions Group, Inc., Polymer Encapsulation
T0767 TechTran Environmental, Inc., RHM-1000 Process
T0772 Terra Vac, Geochemical Fixation
T0790 Textron, Inc., Electro-Hydraulic Scabbling (EHS)
T0798 Thermo Nuclean, Segmented Gate System (SGS)
T0808 Toledo Engineering Company, Inc., High-Temperature Joule-Heated Vitrification
T0818 TVIES, Inc., Soil Washing
T0819 U.S. Department of Energy Laboratories, Enhanced Sludge Washing
T0828 U.S. Geologic Survey, Enzymatic Reduction of Uranium
T0830 U.S. Naval Academy, Air Classifier with Removal of Metals from Soil
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0850 UOP, Ionsiv IE-911 Ion Exchange Resins
T0882 Westinghouse Hanford Company, In Situ Gaseous Reduction System
T0887 Westinghouse Savannah River Corporation, Transportable Vitrification System
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process

VANADIUM

T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0054 Arctech, Inc., Humasorb
T0066 Argonne National Laboratory Transuranium Extraction (TRUEX) Process
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0169 Clemson University, Sintered Ceramic Stabilization
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0200 Delphi Research, Inc., DETOX
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0509 Metal-Based Permeable Reactive Barriers—General

T0510 Metals Recovery, Inc., Metals Leaching
T0583 Oregon State University, Chitosan Beads
T0601 Permeable Reactive Barriers (PRBs)—General
T0668 Rochem Environmental, Inc., Disc Tube
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0692 SCC Environmental, Micro-Flo
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0880 Western Product Recovery Group, Inc., Coordinate Chemical Bonding and Adsorption (CCBA) Process

VOLATILE ORGANIC COMPOUNDS

T0005 Active Environmental Technologies, Inc., TechXtract
T0006 ADTECHS Corporation, E-Process
T0009 Advanced Environmental Services, Inc., System 64MT Low-Temperature Thermal Desorption
T0011 Advanced Microbial Solutions, SuperBio
T0012 Advanced Processing Technologies, Inc., Air-Sparged Hydrocyclone
T0017 Advanced Soil Technologies, Thermal Desorption
T0020 Aeration Basins—General
T0021 Aeromix Systems, Inc., BREEZE
T0024 Air Stripping—General
T0025 Akzo Nobel MPP Systems, Macro Porous Polymer (MPP)
T0027 AlliedSignal Environmental Systems and Services, Inc., Biological Air Treatment (BAT) System
T0029 Alternative Technologies for Waste, Inc., Detoxifier In Situ Steam/Hot-Air Stripping Unit
T0030 Alternative Technologies for Waste, Inc., TerraSure
T0032 Alzeta Corporation, EDGE Thermal Processing Units
T0033 Ambient Engineering, Inc., BIOTON
T0034 American Biotherm, L.L.C., Biotherm Process
T0039 AMETEK Rotron Biofiltration Products, Biocube Aerobic Biofilter
T0047 Aqualogy BioRemedics, Environmental Quality NutriBac
T0048 Aqualogy BioRemedics, Environmental Quality PetroKlenz
T0049 Aqualogy BioRemedics, OptiSorb Encapsulate
T0050 Aquathermolysis—General
T0051 ARC Sonics, Inc., Sonic Reactor (or Sonic Grinder)
T0054 Arctech, Inc., Humasorb
T0057 Arctech, Inc., Ozo-Detox
T0063 Argonne National Laboratory, In-Well Sonication
T0067 Ariel Industries, Inc., Ariel SST Low-Temperature Thermal Desorber
T0068 Armstrong Laboratory Environics Directorate, Phase-Transfer Oxidation
T0069 ARS Technologies, Inc., Ferox, Reduction of Chlorinated Organics in the Vadose Zone
T0070 ARS Technologies, Inc., Pneumatic Fracturing Extraction
T0071 ASTEC, Inc./SPI Division, Low-Temperature Thermal Desorption with Heat Recovery
T0078 Barr Engineering Company, Co-Burning Technology
T0079 BasysTechnologies, Basys Biofilter
T0084 Battelle Pacific Northwest Laboratory, Gas-Phase Corona Reactor

T0090 Beco Engineering Company, Alka/Sorb
T0092 Billings and Associates, Inc., Subsurface Volatilization and Ventilation System
T0095 Bio-Electrics, Inc., Electrofrac Detoxification System
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0100 BioGenesis Enterprises, Inc., Soil Remediation and Cleaning Products
T0104 Biogenie, Inc., Biogenie Biofiltration Process
T0105 Biogenie, Inc., Biogenie Biopile
T0108 Biomin, Inc., Organoclay
T0109 Bio-Reaction Industries, BRI-170/270
T0110 Biorem Technologies, Inc., Soil Pile Bioremediation
T0113 Bioremediation Service, Inc., AquaPlant Biofilter System
T0115 Bioscience, Inc., BIOX Biotreater
T0117 Bioslurping—General
T0119 Biosurfactants—General
T0120 BioSystems Technology, Inc., Biosolids-Enhanced Remediation (BER)
T0122 Biotrickling Filter—General
T0123 BioTrol, Inc., Biological Aqueous Treatment System
T0124 BioTrol, Inc., Soil Washing Technology
T0126 Bioventing—General
T0127 Blast Fracturing—General
T0128 Bogart Environmental Services, Inc., Bevrox Biotreatment
T0130 Bohn Biofilter Corporation, Bohn Off-Gas Treatment
T0135 Calgon Carbon Corporation, Activated Carbon
T0136 Calgon Carbon Oxidation Technologies, Rayox
T0137 Calgon Carbon Oxidation Technologies, Solaqua
T0138 Calgon Carbon Corporation, Perox-Pure
T0142 Carlo Environmental Technologies, Inc., Medium-Temperature Thermal Desorption (MTTD)
T0143 Carson Environmental, Low-Temperature Oxidation
T0144 Carus Chemical Company, CAIROX Potassium Permanganate
T0145 Caswan Environmental Services, Ltd., Thermal Distillation and Recovery
T0146 Catalytic Combustion Corporation, SRCO and HD-SRCO
T0147 Catalytic Oxidation—General
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0152 CerOx Corporation, Mediated Electrochemical Oxidation (MEO)
T0154 CF Systems Corporation, Liquefied Gas Solvent Extraction
T0156 CH2M Hill and Reichhold, Inc., Jet Pump Recovery System
T0159 Charbon Consultants, HCZyme
T0161 Chemical Oxidation—General
T0166 Cintec Environment, Inc., Circulating Fluidized-Bed Combustor (CFBC)
T0167 Clean Technologies, Pyrodigestion
T0168 CleanSoil, Inc., CleanSoil Process
T0171 CMI Corporation, Enviro-Tech Thermal Desorption
T0172 Combustion Process Manufacturing Corporation, CPMC Process
T0173 Commodore Applied Technologies, Inc., Solvated Electron Technology (SET)
T0177 Conor Pacific, WINDsparge
T0178 Constructed Wetlands—General
T0181 Contamination Technologies, Inc., Low-Temperature Thermal Absorber (LTA)
T0182 ConTeck Environmental Services, Inc., Soil Roaster
T0185 Corrpro Companies Inc., Electroremediation
T0187 Covenant Environmental Technologies, Inc., Mobile Retort Unit
T0188 Croy Dewatering & Environmental Services, Inc., Dual-Phase Recovery Unit

T0191 Cunningham-Davis Environmental (CDE Resources, Inc.), ID-20 Chemical Neutralization Process
T0194 Current Environmental Solutions, L.L.C., Six-Phase Soil Heating
T0195 DAHL & Associates, Inc., ThermNet
T0197 Dames and Moore, Two-Phase Vacuum Extraction
T0198 Davis Environmental, Multistage In-Well Aerator
T0199 Dehydro-Tech Corporation, Carver-Greenfield Process
T0200 Delphi Research, Inc., DETOX
T0201 Delta Cooling Towers, Inc., Aqua-Trim and Vanguard Air Strippers
T0202 Detox Industries, Inc., DETOX Process
T0203 Dissolved Air Flotation—General
T0204 Distillation—General
T0205 Diversified Remediation Controls, Inc., Turbostripper
T0206 Divesco, Inc., Soil Washing
T0208 Donald L. Geisel & Associates, Inc., HeatTrode Thermally Accelerated In Situ Bioremediation
T0210 Dow Chemical Company, Dowex Optipore
T0212 Dual-Phase Extraction—General
T0213 Duke Engineering & Services, Inc., Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)
T0215 DuraTherm, Inc., DuraTherm Desorption
T0219 E Products, Inc., Venturi Thermal Oxidizer
T0222 Earth Purification Engineering, Inc., Soil Cleanup System (SCS)
T0224 ECO Purification Systems USA, Inc., ECOCHOICE
T0225 Ecology Technologies International, Inc., FyreZyme
T0226 Ecolotree, Inc., Ecolotree Buffer
T0227 Ecolotree, Inc., Ecolotree Cap
T0228 ECO-TEC, Inc., EnviroMech Gold Biocatalytic Contaminant Degradation
T0231 EFX Systems, Inc., Granular Activated Carbon–Fluidized-Bed Reactor (GAC FBR) Process
T0233 Ejector Systems, Inc., VESTRIP
T0236 Electrokinetic Remediation—General
T0237 Electrokinetically Enhanced Bioremediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0239 Electro-Petroleum, Inc., Electrokinetic Treatment
T0242 ELI Eco Logic International, Inc., Gas-Phase Chemical Reduction (GPCR)
T0248 ENERGIA, Inc., Reductive Photo-Dechlorination (RPD)
T0250 Energy and Environmental Research Corporation, Reactor Filter System
T0252 Energy Products of Idaho, Fluidized-Bed Combustion
T0253 Energy Reclamation, Inc., Pyrolytic Waste Reclamation (PWR)
T0256 Ensite, Inc., SafeSoil
T0257 EnSolve Biosystems, Inc., EnCell Bioreactor
T0259 ENSR International Group, Biovault
T0260 ENSR International Group, Soil Cleaning Process
T0263 Envirogen, Adhesive-Deficient Bacteria
T0264 Envirogen, TCE-Degrading Bacteria
T0267 Envirogen, Inc., Spartech
T0268 Envirogen, Inc., VaporTech Enhanced Volatilization
T0269 Enviro-Klean Technologies, Inc., KLEAN-MACHINE
T0271 EnviroMetal Technologies, Inc., EnviroMetal Process
T0274 Environmental Dynamics, Low-Temperature Plasma
T0275 Environmental Fuel Systems, Inc., Reclaim
T0277 Environmental Remediation Consultants, Inc., Biointegration

T0278 Environmental Remediation International (EnRem), Ltd., Soil Remediation System (SRS)
T0281 Environmental Resources Management Corporation (ERM), Advanced Fluidized Composting (AFC)
T0282 Environmental Soil Management, Inc., Low-Temperature Thermal Desorption
T0288 Enviro-Sciences, Inc., Low-Energy Extraction Process (LEEP)
T0289 EnviroSep, Inc., Thick-Film Absorption (TFA)
T0290 Enviro-Soil Remediation, Inc., Thermal Stripping
T0293 Enzyme Technologies, Inc., Dissolved Oxygen In Situ Treatment (DO IT)
T0294 Enzyme Technologies, Inc., Multienzyme Complex (MZC)
T0296 EPG Companies, Inc., Oxidair Thermal Oxidizers
T0299 ETG Environmental, Inc., Thermo-O-Detox Medium-Temperature Thermal Desorption (MTTD)
T0300 ETUS, Inc., Enhanced Bioremediation
T0302 Excimer Laser-Assisted Destruction of Organic Molecules—General
T0303 Extraksol (vendor unknown)
T0306 Ferro Corporation, Waste Vitrification through Electric Melting
T0308 First Environment, Inc., FE ACTIVE
T0309 Fixed-Bed Soil Biofilters—General
T0310 Fluidized-Bed Thermal Oxidation—General
T0311 FOREMOST Solutions, Inc., Bioluxes and BioNet
T0318 FRX, Inc., Hydraulic Fracturing
T0319 FTC Acquisition Corporation, DirCon Freeze Crystallization Process
T0320 Funderburk & Associates, Solidification Process
T0323 G.E.M., Inc., Chemical Treatment
T0329 General Atomics, Supercritical Water Oxidation
T0331 Genesis Eco Systems, Inc., Soil Treatment and Recycling
T0332 GeneSyst International, Inc., Supercritical Gravity Pressure Vessel
T0333 Geo-Cleanse International, Inc., Geo-Cleanse Process
T0334 Geo-Con Inc., Shallow Soil Mixing/Thermally Enhanced Vapor Extraction
T0335 Geo-Con, Inc., Deep Soil Mixing
T0336 Geo-Con, Inc., Shallow Soil Mixing
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0344 Geosafe Corporation, In Situ Vitrification
T0346 Geotech Environmental Equipment, Inc., Scavenger Recovery Systems
T0348 GHEA Associates, Soil Washing Technology
T0350 Global Technologies, Chloro-Cat Catalytic Oxidizer
T0351 Golder Applied Technologies, Inc., Hydraulic Fracturing/FracTool
T0352 Golder Associates Corporation, Montan Wax Barrier
T0354 Grace Bioremediation Technologies, Daramend Bioremediation Technology
T0355 Granular Activated Carbon (GAC)—General
T0357 GSE Lining Technology, Inc., GSE CurtainWall Vertical Membrane Barrier System
T0358 GSE Lining Technology, Inc., GSE GundWall Vertical Membrane Barrier Systems
T0360 H&H Eco Systems, Inc., Microenfractionator
T0361 H&H Eco Systems, Inc., Solid-State Chemical Oxidation
T0363 Harding ESE, Inc., PetroClean Bioremediation System
T0365 Harding ESE, Inc., Composting
T0366 Harding ESE, Inc., Forced Aeration Contaminant Treatment (FACT)
T0367 Harding ESE, Inc., In Situ Vadose Zone Soil Treatment
T0368 Harding ESE, Inc., Two-Zone Plume Interception Treatment Technology
T0370 High Mesa Technologies, L.L.C., Silent Discharge Plasma
T0371 High Voltage Environmental Applications, Inc., High-Energy Electron Beam Irradiation

T0373 Horizontal Drilling—General
T0374 Horizontal Technologies, Inc., Linear Containment Remediation System
T0379 Hrubetz Environmental Services, Inc., HRUBOUT Process In Situ
T0380 Hrubetz Environmental Services, Inc., HRUBOUT Process, Ex Situ
T0381 Hughes Environmental Systems, Inc., In Situ Steam-Enhanced Recovery Process
T0383 Huntington Environmental Systems, Econ-Abator Catalytic Oxidation System
T0384 Hydraulic Fracturing—General
T0385 Hydriplex, Inc., HP-80 Solution and Hydrocleaner 20-10 System
T0388 Hydrogen Peroxide In Situ Bioremediation—General
T0396 IEG Technologies Corporation, Coaxial Groundwater Ventilation (KGB)
T0397 IEG Technologies Corporation, Soil Air Circulation (BLK)
T0398 IEG Technologies Corporation, Vacuum Vaporizer Well (UVB)
T0400 IIT Research Institute, Radio Frequency Heating
T0401 Imbibitive Technologies Corporation (IM-TECH), Imbiber Beads
T0403 IM-TECH, Solidification/Stabilization Process
T0405 In Situ Oil Skimmers—General
T0406 In Situ Soil Vapor Extraction (SVE)—General
T0407 In Situ Steam-Enhanced Extraction—General
T0408 In-Situ Fixation, Inc., Dual Auger System
T0409 In Situ Oxidative Technologies, Inc. (ISOTEC Inc.), ISOTEC
T0412 Institute of Gas Technology, MGP-REM
T0420 Integrated Environmental Solutions, Inc., Quick-Purge
T0425 International Environmental Technologies, Inc. (IET), Biodrain
T0431 IT Corporation, Batch Steam Distillation and Metals Extraction
T0433 IT Corporation, Biofast
T0437 IT Corporation, Engineered Bioremediation System
T0438 IT Corporation, Enhanced Natural Degradation (END)
T0439 IT Corporation, Fluid Injection with Vacuum Extraction
T0441 IT Corporation, Hybrid Thermal Treatment System (HTTS)
T0442 IT Corporation, In Situ Air Sparging
T0444 IT Corporation, Oxygen Microbubble In Situ Bioremediation
T0445 IT Corporation, Ozonation
T0447 IT Corporation, Slurry-Phase Bioremediation—Full Scale
T0449 IT Corporation, Thermal Desorption
T0453 Kaiser-Hill Company, L.L.C., Supercritical Carbon Dioxide Extraction
T0454 KAL CON Environmental Services, Thermal Desorption
T0459 King, Buck Technologies, Inc., HD CatOx System
T0460 King, Buck Technologies, Inc., MultiMode Combustion
T0461 Kinit Enterprises, Trozone Soil Remediation System
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0467 KSE, Inc., AIR-II Process
T0468 KVA, C-Sparger System
T0470 Lambda Bioremediation Systems, Inc., Bioremediation
T0473 Lawrence Livermore National Laboratory, Direct Chemical Oxidation
T0474 Lawrence Livermore National Laboratory, Hot-Recycled-Solid (HRS) Retorting Process
T0487 Louisiana State University, Colloidal Gas Aphron
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0491 MACTEC, Inc., Chemical Oxidation (ChemOx) Process
T0492 Magnum Water Technology, CAV-OX Cavitation Oxidation Technology
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0494 ManTech Environmental Corporation, CleanOX Process

T0495 Maple Engineering Services, Inc., Biopur
T0497 Massachusetts Institute of Technology, Tunable Hybrid Plasma
T0498 Matrix Photocatalytic, Inc., TiO_2 Photocatalytic Treatment System
T0499 Maxymillian Technologies, Inc., Indirect System
T0500 Maxymillian Technologies, Inc., Thermal Desorption System
T0502 McLaren/Hart, Inc., IRV-100, IRV-150, and IRV-200 Thermal Desorption Systems
T0503 Media and Process Technology, Inc., Bioscrubber
T0505 MeltTran, Inc., Ultimate Solution
T0506 Membran Corporation, Membrane Gas Transfer
T0507 Membrane Technology and Research, Inc., VaporSep Membrane Recovery System
T0509 Metal-Based Permeable Reactive Barriers—General
T0511 Metals Removal Via Peat—General
T0512 Metcalf & Eddy, Aqua-Sparg
T0520 Methanotrophic Biofilters—General
T0522 Micro-Bac International, Inc., M-1000 Series Bioremediation Products
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0528 Midwest Soil Remediation, Inc., GEM-1000 Low-Temperature Thermal Desorption
T0529 Millgard Corporation, MecTool Remediation System
T0530 MIOX Corporation, Miox System
T0536 Molten Salt Oxidation—General
T0537 Monsanto Company, Lasagna
T0541 MYCELX Technologies Corporation, MYCELX
T0544 National Renewable Energy Laboratory, Solar Detoxification of Water
T0546 Natural Attenuation—General
T0547 NEPCCO Environmental Systems, SoilPurge
T0548 NEPCCO Environmental Systems, SpargePurge
T0549 NEPCCO Environmental Systems, TurboTray Air Stripper
T0551 NEPCCO Environmental Systems, VaporPurge
T0552 NEPCCO, Photocatalytic Oxidation Technology
T0555 Niaski Environmental, Inc., Biopurge
T0556 Niaski Environmental, Inc., BioSparge System
T0561 North American Drilling Technologies (NADT), Inc., EnviroZyme
T0563 North American Technologies Group/InPlant, Inc., SFC Oleofiltration Technology
T0564 North East Environmental Products, Inc., ShallowTray Air Stripper
T0566 NUCON International, Inc., Brayton Cycle
T0568 Oak Hill Company, Ltd., In Situ Saturated Zone Treatment
T0571 Oak Ridge National Laboratory, In Situ Chemical Oxidation through Recirculation (ISCOR)
T0573 O'Brien & Gere Engineers, Inc., Mechanical Volatilization Screening
T0577 On-Site Technologies, Modular Interchangeable Treatment System (MITS)
T0579 On-Site Thermal Services Division of Soil Restoration and Recycling, L.L.C., Low-Temperature Thermal Desorption Plant
T0582 Onyx Industrial Services, SOIL*EX
T0585 Oxidation Systems, Inc., HYDROX Oxidation Process
T0586 Pacific Northwest National Laboratory, In Situ Redox Manipulation
T0591 Paragon Environmental Systems, Inc., Paragon SVE/Oxidizers
T0592 Passive Soil Vapor Extraction—General
T0595 Peat/Compost Biofiltration—General
T0597 Pedco, Inc., Rotary Cascading Bed Incineration
T0599 PerkinElmer, Inc., NoVOCs
T0601 Permeable Reactive Barriers (PRBs)—General
T0602 Pet-Con Soil Remediation, Inc., Thermal Desorption

T0606 PHYTOKinetics, Inc., Phytoremediation
T0607 Phytoremediation—General
T0609 PhytoWorks, Inc., Mercury Removal Using Genetically Engineered Plants
T0610 Pile Biodegradation (Biopile)—Multiple Vendors
T0612 Plasma Environmental Technologies, Inc., Plasma Arcing Conversion (PARCON) Unit
T0613 Plasma Vitrification—General
T0617 PPC Biofilter, Biofiltration Systems
T0618 Praxair, Inc., MixFlo
T0619 Praxair, Inc., Oxygen Combustion System
T0620 Praxis Environmental Technologies, Inc., In Situ Thermal Extraction
T0621 Pressure Dewatering—General
T0625 Process Technologies, Inc., Photolytic Destruction Technology
T0629 Pulse Sciences, Inc., X-Ray Treatment
T0630 Purgo, Inc., Portable Anaerobic Thermal Desorption Unit (ATDU)
T0631 Purus, Inc., Pulsed UV Irradiation
T0632 Pyrolysis—General
T0634 QED Environmental Systems, Stackable Tray Air Strippers
T0636 Quad Environmental Technologies Corporation, Chemtact Gaseous Waste Treatment
T0638 R.E. Wright Environmental, Inc., Steam-Enhanced Recovery
T0639 R.E. Wright Environmental, Inc., In Situ Bioremediation Treatment System
T0640 Radian International, L.L.C., Aeration Curtain
T0641 Radian International, L.L.C., Aquadetox/Soil Vapor Extraction (SVE)
T0645 Recycling Science International, Inc., Desorption and Vapor Extraction (DAVE) System
T0649 Regenesis Bioremediation Products, Inc., Hydrogen Release Compound (HRC)
T0650 Regenesis Bioremediation Products, Inc., Oxygen Release Compound (ORC)
T0654 Remediation Service International, Internal Combustion Engine (ICE)
T0655 Remediation Service International, Spray Aeration Vacuum Extraction (SAVE) System
T0656 Remtech Engineers, Bubble Lance Low-Profile Diffused Air Stripper
T0659 Resources Conservation Company, Basic Extractive Sludge Treatment (BEST)
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0662 RGF Environmental Group, CO3P System
T0664 RKK-SoilFreeze Technologies, L.L.C., CRYOCELL
T0665 RKK-SoilFreeze Technologies, L.L.C., CRYOSWEEP
T0668 Rochem Environmental, Inc., Disc Tube
T0671 Rohm and Haas Company, Ambersorb 563 Adsorbent
T0672 Rohm and Haas Company, Ambersorb 600
T0673 Rotating Biological Contactors—General
T0674 Roy F. Weston, Inc., Low-Temperature Thermal Treatment (LT3)
T0676 Rusmar, Inc., Long-Duration Foam
T0677 Rust Federal Services, Inc., VAC*TRAX Thermal Desorption
T0683 Sandia National Laboratory and Illinois Institute of Technology, Thermally Enhanced Vapor Extraction System (TEVES)
T0688 Savannah River Ecology Laboratory, Selective Colloid Mobilization
T0689 SBP Technologies, Inc., Membrane Filtration
T0691 SBP Technologies, Inc., Solid-Phase Bioremediation
T0694 Schonberg Radiation Corporation, Toxic Remediation Using Radiation
T0695 Science & Engineering Associates, Inc., Barometrically Enhanced Remediation Technology (BERT)
T0696 Science Applications International Corporation, Plasma Hearth Process

T0698 Scientific Ecology Group (SEG), Steam Reforming—Synthetica Technologies Detoxifier (STD)
T0700 Seaview Thermal Systems, High-Temperature Thermal Distillation
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0705 Separation and Recovery Systems, Inc., SAREX Chemical Fixation Process
T0706 Separation and Recovery Systems, Inc., SAREX Process
T0712 SIVE Services, Steam Injection and Vacuum Extraction (SIVE)
T0715 Smith Technology Corporation, Low-Temperature Thermal Aeration (LTTA)
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0717 Smith Technology Corporation, SoilTech Anaerobic Thermal Processor (ATP)
T0718 Smith Technology Corporation, Two-Phase Vacuum Extraction
T0719 Soil/Sediment Washing—General
T0721 Soil Flushing—General
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0731 Solvay Interox, Inc., ENVIROFirst Granules
T0732 Solvent Extraction—General
T0733 Sonotech, Inc., Cello Pulse Combustion Burner System
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0739 SRE, Inc., Solv-ex
T0744 Startech Environmental Corporation, Plasma Waste Converter
T0745 State University of New York, Oswego, Electrochemical Peroxidation (ECP)
T0747 SteamTech Environmental Services and Integrated Water Resources, Inc., Steam-Enhanced Extraction (SEE)
T0748 SteamTech, Inc., and Integrated Water Technologies, Inc., Dynamic Underground Stripping (DUS)
T0749 SteamTech, Inc., and Integrated Water Technologies, Inc., In Situ Hydrous Pyrolysis/Oxidation (HPO)
T0750 Stevens Institute of Technology, Trench Bio-Sparge
T0751 Stevenson & Palmer Engineering, Inc., PHOSter
T0753 Summit Research Corporation, Supercritical Water Oxidation
T0755 Supercritical Carbon Dioxide Extraction—General
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0759 Surfactants—General
T0762 Syracuse University, Supercritical Fluid Extraction
T0764 Tarmac Environmental Company, Inc., Thermal Desorption
T0768 Tekno Associates, Biolift
T0769 Terra Resources, Ltd., Terra Wash Soil Washing
T0770 Terra Systems, Inc., In Situ Bioremediation (ISB)
T0771 Terra Vac, DNAPL Vaporization
T0774 Terra Vac, Inc., Biovac
T0775 Terra Vac, Inc., Dual-Vacuum Extraction
T0776 Terra Vac, Inc., Oxy Vac
T0777 Terra Vac, Inc., Pneumatic Soil Fracturing (PSF)
T0778 Terra Vac, Inc., Sparge VAC
T0779 Terra Vac, Inc., Vacuum Extraction
T0780 Terra Vac, Soil Heating
T0783 Terrapure Systems, L.L.C., Palladized Iron Remediation Technology
T0784 TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption
T0785 TerraTherm Environmental Services, Inc., Thermal Wells
T0787 Texaco, Inc., Texaco Gasification Process
T0788 Texas A&M University, Low-Pressure Surface Wave Plasma Reactor

T0792 The Westford Chemical Corporation, BioSolv
T0794 Thermal Desorption—General
T0795 Thermatrix, Inc., Flameless Thermal Oxidizer (FTO)
T0796 Thermatrix, Inc., PADRE Air Treatment Systems
T0797 Thermo Design Engineering, Ltd., Clean Soil Process (CSP)
T0802 ThermoRetec, Microbial Fence
T0805 ThermoRetec, Thermatek Thermal Desorption
T0807 Thorneco, Inc., Enzyme-Activated Cellulose Technology
T0810 Toxic Environmental Control Systems, Inc., Electrode-Assisted Soil Washing
T0811 TPS Technologies, Inc., Thermal Desorption
T0812 Trans Coastal Marine Services, Bioplug/Bioconduit
T0817 T-Thermal Company, Submerged Quench Incineration
T0823 U.S. Filter Corporation, PO*WW*ER Wastewater Treatment System
T0826 U.S. Filter/Zimpro Products, Powdered Activated Carbon Treatment (PACT)
T0827 U.S. Filter/Zimpro Products, Wet Air Oxidation
T0829 U.S. Microbics, Inc., Bio-Raptor
T0831 U.S. Waste Thermal Processing, Model 100 Mobile Thermal Processor
T0833 Ultraviolet Oxidation (UV/Oxidation)—General
T0834 Ultrox International/U.S. Filter, ULTROX Advanced Oxidation Process
T0835 Umpqua Research Company, Low-Temperature Aqueous-Phase Catalytic Oxidation
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0841 University of Akron, Sonochemical Destruction
T0844 University of Connecticut, Contaminant Absorption and Recovery
T0845 University of Dayton Research Institute, Photothermal Detoxification Unit
T0852 US EPA Risk Reduction Engineering Laboratory, Mobile Volume Reduction Unit (VRU)
T0853 UV Technologies, Inc., UV-CATOX Technology
T0855 Vapor-Phase Biofiltration—General
T0863 W.E.S., Inc., Microb-Sparging
T0864 Walker Process Equipment, EnviroDisc Rotating Biological Contactors
T0865 Wasatch Environmental, Inc., Density-Driven Convection (DDC)
T0866 Washington Group International and Spetstamponazhgeologia Enterprises, Clay-Based Grouting Technique
T0868 Waste Management, Inc., X*TRAX Thermal Desorption
T0869 Waste Microbes International (WMI), Inc., WMI-2000
T0870 Waste Stream Technology, Inc., Bioremediation
T0871 WASTECH, Inc., Solidification and Stabilization
T0873 Water Equipment Services, Inc., Environmental Division Vacu-Point
T0881 Western Research Institute, Contained Recovery of Oily Wastes (CROW)
T0884 Westinghouse Savannah River Company, In Situ Bioremediation of Chlorinated Solvents with Natural Gas
T0885 Westinghouse Savannah River Company, In Situ Air Stripping
T0886 Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI), GeoSiphon
T0888 Wet Oxidation—General
T0889 White-Rot Fungus—General
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0893 WRS Infrastructure & Environmental, Inc., Thermal Desorption Unit
T0894 Xerox Corporation, Two-Phase Extraction System
T0897 Yellowstone Environmental Science, Inc. (YES), Biocat
T0898 Zapit Technology, Inc., Zapit Processing Unit
T0899 Zenon Environmental Systems, Inc., ZenoGem

T0900 Zenon Environmental, Inc., Cross-Flow Pervaporation System
T0901 Zeros USA, Inc., Zero-Emission Energy Recycling System (ZEROS)

ZINC

T0001 3M Company, 3M Empore Extraction Disk
T0005 Active Environmental Technologies, Inc., TechXtract
T0015 Advanced Recovery Systems, Inc., DeHg
T0022 Aero-Terra-Aqua Technologies Corporation, Aqua-Fix
T0023 Affinity Water Technologies, Advanced Affinity Chromatography
T0040 Andco Environmental Processes, Inc., Electrochemical Iron Generation
T0042 Applied Environmental Services, Inc., Asphaltic Metals Stabilization
T0052 ARCADIS Geraghty and Miller, In Situ Reactive Zones Using Molasses
T0054 Arctech, Inc., Humasorb
T0076 B & W Services, Inc., Cyclone Furnace Vitrification
T0080 Battelle Memorial Institute, Electroacoustic Dewatering
T0099 BioGenesis Enterprises, Inc., Soil and Sediment Washing Process
T0107 Biomet Mining Solutions Corporation, Biosulfide Process
T0118 Biosorption—General
T0124 BioTrol, Inc., Soil Washing Technology
T0131 Brice Environmental Services Corporation (BESCORP), Soil Washing System (BSWS)
T0132 Brookhaven National Laboratory, Biochemical Recovery of Radionuclides and Heavy Metals
T0148 CBA Environmental Services, Inc., Mobile Injection Treatment Unit (MITU)
T0149 Cement-Based Stabilization/Solidification—General
T0150 Cement-Lock, L.L.C., Cement-Lock Technology
T0151 Ceramic Immobilization of Radioactive Wastes—General
T0155 CFX Corporation, CFX MiniFix
T0158 CH2M Hill, Phytoremediation-Based Systems
T0160 Chemfix Technologies, Inc., Chemfix Solidification/Stabilization Technology
T0162 Chemical Precipitation of Metals—General
T0169 Clemson University, Sintered Ceramic Stabilization
T0174 Commodore Separation Technologies, Inc., Supported Liquid Membrane
T0176 Concurrent Technologies Corporation, Acid Extraction Treatment System (AETS)
T0178 Constructed Wetlands—General
T0179 Constructed Wetlands for Acid Mine Drainage—General
T0185 Corrpro Companies Inc., Electroremediation
T0192 CURE International, Inc., CURE Electrocoagulation Wastewater Treatment System
T0207 Doe Run Company, TERRAMET Heavy-Metal Removal Technology
T0214 DuPont/Oberlin, Microfiltration Technology
T0218 Dynaphore, Inc., Forager Sponge Technology
T0229 Edenspace Systems Corporation, Hyperaccumulation of Metals
T0232 Eichrom Industries, Inc., Diphonix
T0235 Electrochemical Treatment of Contaminated Groundwater—General
T0236 Electrokinetic Remediation—General
T0238 Electrokinetics, Inc., Electrokinetic Soil Cleaning
T0279 Environmental Research and Development, Inc, Neutral Process for Heavy-Metals Removal
T0280 Environmental Research and Development, Inc., Ice Electrode
T0291 EnviroSource Technologies, Inc., Super Detox Process
T0297 EPOC Water, Inc., Microfiltration Technology (EXXFLOW and EXXPRESS)

T0301 Evaporation for Wastewater Treatment—General
T0306 Ferro Corporation, Waste Vitrification through Electric Melting
T0307 Filter Flow Technology, Inc., Colloid-Polishing Filter Method
T0313 Forrester Environmental Services, Inc., Stabilization of Lead-Bearing Waste
T0320 Funderburk & Associates, Solidification Process
T0337 Geokinetics International, Inc., Pool Process Electrokinetic Remediation
T0344 Geosafe Corporation, In Situ Vitrification
T0348 GHEA Associates, Soil Washing Technology
T0377 Horsehead Resource Development Company, Inc., Flame Reactor
T0378 HPT Research, Inc., Ionic State Modification (ISM) Process for the Treatment of Acid Mine Drainage
T0390 IBC Advanced Technologies, Inc., SuperLig Ion Exchange Resins
T0394 Idaho National Engineering Laboratory/Brookhaven National Laboratory, Modified Sulfur Cement Encapsulation
T0426 International Environmental Trading Company, Inc., Metals Extraction and Recycling System
T0443 IT Corporation, In Situ Geochemical Fixation
T0452 Joule-Heated Vitrification—General
T0461 Kinit Enterprises, Trozone Soil Remediation System
T0462 Klean Earth Environmental Company (KEECO, Inc.), KB-1
T0463 Klean Earth Environmental Company (KEECO, Inc.), KB-SEA
T0464 Klean Earth Environmental Company (KEECO, Inc.), Meta-Lock
T0465 Klohn-Crippen Consultants, Ltd., ChemTech Soil Treatment Process
T0469 Kvaerner Metals, Resin-in-Pulp/Carbon-in-Pulp
T0471 Lawrence Livermore National Laboratory, Carbon Aerogel Capacitive Deionization of Water
T0477 Lehigh University, Hybrid Inorganic Solvent HISORB
T0478 Lewis Environmental Services, Inc., Soil-Leaching and Enviro-Clean Technologies
T0480 Linatex, Inc., Soil/Sediment Washing Technology
T0488 Lynntech, Inc., Electrokinetic Remediation of Contaminated Soil
T0490 M4 Environmental, L.P., Catalytic Extraction Process
T0493 ManTech Environmental Corporation, ElectroChemical GeoOxidation (ECGO)
T0510 Metals Recovery, Inc., Metals Leaching
T0515 Metcalf & Eddy, Inc., Hydro-Sep Soil Washing Technology
T0517 Metcalf & Eddy, Inc., SOLFIX
T0518 Met-Chem, Metal Kleen A
T0519 Met-Chem, Metal Kleen B (MCB)
T0521 Met-Tech, Inc., Metal Separation by Liquid Ion Exchange
T0523 Microbe Technology Corporation, Bac-Terra Remedial Technology
T0525 Microbial & Aquatic Treatment Systems, Inc. (MATS), Biomats
T0529 Millgard Corporation, MecTool Remediation System
T0533 Molasses Treatment for Bioremediation—General
T0535 Molten Metal Technology, Inc., Quantum Catalytic Extraction Process (Q-CEP)
T0541 MYCELX Technologies Corporation, MYCELX
T0545 National Research Council of Canada, Solvent Extraction Soil Remediation
T0546 Natural Attenuation—General
T0560 Normrock Industries, Inc., Amphibex Excavator
T0562 North American Technologies Group, Inc., System IV
T0583 Oregon State University, Chitosan Beads
T0593 Peat Technologies Corporation, MultiSorb 100 Adsorbent Media
T0601 Permeable Reactive Barriers (PRBs)—General
T0605 Physical Sciences, Inc., Metals Immobilization and Decontamination of Aggregate Solids (MeIDAS)

T0607 Phytoremediation—General
T0608 Phytoremediation: Hyperaccumulation—General
T0611 Pintail Systems, Inc., Spent-Ore Bioremediation Process
T0613 Plasma Vitrification—General
T0614 PolyIonix Separation Technologies, Inc., Polymer Filtration System
T0615 Polymer-Based Solidification/Stabilization—General
T0616 Pozzolanic Solidification/Stabilization—General
T0622 Pressure Systems, Inc., Phoenix Ash Technology
T0624 Proactive Applied Solutions Corporation, LEADX
T0644 Recra Environmental, Inc., Alternating Current Electrocoagulation
T0658 Resource Management and Recovery, AlgaSORB
T0660 Retech, Inc., Plasma Arc Centrifugal Treatment (PACT) System
T0661 Reverse Osmosis—General
T0667 RMT, Inc., Metal Treatment Technology (MTTTM)
T0669 Rocky Mountain Remediation Services, L.L.C., Envirobond and Envirobric
T0686 Sanexen Environmental Services, Inc., Ultrasorption
T0692 SCC Environmental, Micro-Flo
T0701 Seiler Pollution Control Systems, High-Temperature Vitrification System
T0703 Selective Environmental Technologies, Inc., ACT*DE*CON
T0704 Selective Environmental Technologies, Inc., MAG*SEP
T0709 Sevenson Environmental Services, Inc. MAECTITE Chemical Treatment Process
T0716 Smith Technology Corporation, Pyrokiln Thermal Encapsulation
T0719 Soil/Sediment Washing—General
T0726 Solidification/Stabilization—General
T0727 Soliditech, Inc., Soliditech Solidification and Stabilization Process
T0730 Solucorp Industries, Ltd., Molecular Bonding System
T0736 SOUND/epic, Dispersion by Chemical Reaction (DCR) Technology
T0746 STC Remediation, Inc., Solidification/Stabilization Technology
T0756 Supercritical Water Oxidation—General
T0757 Surbec Environmental, L.L.C., Soil Washing Technology
T0763 Tallon, Inc., Virtokele
T0765 Technology Scientific, Ltd., Flow Consecutor Technology (FCT)
T0789 Texilla Environmental, Inc., Synthetic Mineral Immobilization Technology (SMITE)
T0801 Thermoplastic Stabilization/Solidification—General
T0810 Toxic Environmental Control Systems, Inc., Electrode-Assisted Soil Washing
T0818 TVIES, Inc., Soil Washing
T0819 U.S. Department of Energy Laboratories, Enhanced Sludge Washing
T0824 U.S. Filter Corporation, WESPHix
T0832 UFA Ventures, Inc., Phosphate-Induced Metal Stabilization (PIMS)
T0838 United Retek Corporation, Asphalt Emulsion Stabilization
T0862 Vortec Corporation, Cyclone Melting System (CMS)
T0874 Water Technology International Corporation, Self-Sealing/Self-Healing Barrier (SS/SH)
T0875 Waterloo Barrier, Inc., Waterloo Barrier
T0880 Western Product Recovery Group, Inc., Coordinate Chemical Bonding and Adsorption (CCBA) Process
T0887 Westinghouse Savannah River Corporation, Transportable Vitrification System
T0892 WRS Infrastructure & Environmental, Inc., Soil Washing Process
T0896 Yellowstone Environmental Science, Inc. (YES), Biocat II
T0899 Zenon Environmental Systems, Inc., ZenoGem

ZIRCONIUM

TECHNOLOGIES WITH ABSTRACTS AND TECHNOLOGY COSTS

T0001

3M Corporation

3M Empore Extraction Disk

Abstract
The 3M™ Empore™ extraction disk is an ex situ separation technology that uses a netlike, Teflon [polytetrafluoroethylene (PTFE)] matrix to enmesh sorbents or ion exchange materials. The sorbents are selected to remove specific contaminants from aqueous waste. 3M has developed Empore extraction disks for the removal of total petroleum hydrocarbons (TPH), oils, grease, polychlorinated biphenyls (PCBs), cyanides, heavy metals, radionuclides, pesticides, herbicides, halogenated and nonhalogenated semivolatile organic compounds (SVOCs), explosives, polycyclic aromatic hydrocarbons (PAHs), dioxins, furans, and halogenated organic solvents. During remediation applications, the Empore extraction disk is loaded on a filter cartridge and used as part of a modular remediation system. The Empore membrane may also be used to collect and analyze samples in the field or in the laboratory.

Empore extraction disks for analytical applications are commercially available. The Empore remediation cartridges and systems are not commercially available; however, they may be custom designed for a specific project. 3M is currently determining the best way to meet the needs of the industry before commercially offering remediation systems.

The vendor claims that the 3M Empore extraction disk technology has several advantages:

- Allows for flow rates that are 10 to 100 times greater than ion exchange columns.
- Uses chemical sorbent powders that previously could not be used in a practical engineered form due to small particle size.

Wiley's Remediation Technologies Handbook: Major Contaminant Chemicals and Chemical Groups. By Jay H. Lehr
ISBN 0-471-45599-7

- Yields more complete decontamination than existing ion exchange columns.
- Produces a final waste form that takes up less volume and can be handled with less worker exposure to radiation.

High concentration of nontargeted ionic contaminants may reduce the efficiency of the 3M Empore extraction disk. Due to the high loading capabilities of the Empore membranes, the radionuclide concentration on the filters must be monitored to ensure that the membranes do not exceed the limits for low-level radioactive waste.

Technology Cost

In 1996, the U.S. Department of Energy (DOE) Office of Science and Technology's Decontamination and Decommissioning Focus Area conducted a pilot-scale demonstration of the Empore extraction disk technology at the Chicago Pile-5 Research Reactor at the DOE's Argonne National Laboratory–East in Argonne, Illinois. The Empore system was used to treat 4500 gal of water contaminated with radioactive cesium and cobalt. Researchers calculated costs for the technology based on this demonstration. If the Empore disks were used to remediate the entire 24,000-gal storage tank at a rate of 650 gal/day, the cost of the project would average $1.71/gal. This estimate included the costs for labor and materials and excluded mobilization and demobilization costs (D20905C, p. 12).

In 2000, the vendor estimated that labor and materials for a 5-gal/min Empore remediation system would cost $15,000. The labor and materials costs for a 50-gal/min system would be approximately $25,000 (D20905C, p. 12).

Empore extraction disks are loaded with different sorbents to target specific contaminants. The cost of the Empore cartridges designed for remediation will depend upon the contaminant and the size of the order. During the Chicago Pile-5 demonstration, an Empore extraction disk was loaded with CoHex ion exchange material and used to remove cesium from the contaminated water. An order of 10 Empore CoHex exchange cartridges cost $2000 (D20905C, p. 12).

Information Source

D20905C, U.S. DOE, 2000

T0002

7-7, Inc.

Liquefication Process

Abstract

The 7-7 Inc. (7-7) liquefication process is a system for liquefying coal tars from coal tar bottoms generated in the production of coke and similar coal tar wastes. The resulting liquified coal tar can then be used as a raw material by commercial coal tar processing facilities.

From September of 1991 to April of 1993, 7-7 designed, built, and obtained the patent rights to a tar solids liquefication system. The system is currently commercially available and has been demonstrated at full scale.

This technology does not fully decontaminate the wastes but instead processes the waste so that a portion of it can be recycled.

Technology Cost

The 7-7, Inc. (7-7) liquefication process was used at the Broderick Wood Products Superfund site, a former wood treating plant near Denver, Colorado. More than 3200 yd^3 of creosote sludge were removed and recovered. The on-site liquefication of the sludge cost approximately $1,000,000. No information was available as to what these costs covered (D16170G).

Information Source

D16170G, DeFeo, 1994

T0003

Abanaki Corporation

Active Belt Oil Skimmers

Abstract
Abanaki Corporation manufactures a range of belt oil skimmers that can be used to recover oil products from water. The skimmers use the differences in specific gravity and surface tension between oil and water to remove oil from contaminated groundwater, wastewaters, surface waters, or coolant.

The Abanaki Corporation produces small, portable skimmers such as the Mighty Mini®, the Duro Mini®, and the Tote-It®. The Oil Grabber® models may be equipped with varying sizes and number of belts for medium to large jobs. Abanaki's Oil Boss® unit works well under harsh or moist conditions. The Grease Grabber® is specially designed to skim heavy oil and grease. The PetroXtractor® is used to remediate groundwater in situ.

Abanaki Corporation has been manufacturing this type of equipment since 1968. The technology has been used for industrial applications for many years and is commercially available.

According to the vendor, Abanaki oil skimmers have the following advantages:

- Separate oil and elevate it up to 100 ft without a pump.
- Remove very little water.
- Maintain skimming efficiency through fluctuating water levels.
- Reduce fluid disposal costs.
- System is dependable and cost effective.
- Skimmed oil can be recycled and reused as lubricant or fuel.

If the oil or grease congeals or solidifies at ambient temperatures, the tank and/or skimmer will require heaters to maintain fluid flow. This is especially true at temperatures where water freezes. The use of rust inhibitors, high temperatures, and variable pH levels can affect the efficiency of oil skimmers. Turbulent waters may emulsify the water and oil and limit the system effectiveness. All information is from the vendor and has not been independently verified.

Technology Cost
The base price is $1490 for a 1- or 2-inch PetroXtractor® skimmer and $1590 for a 4-inch skimmer (Personal communication, Abanaki Corporation, 1997).

The cost to add screening and skimming equipment to wastewater tanks at a food processing facility in Ontario, Canada, was 17,000 Canadian dollars (D179082, p. 23).

Information Source

D179082, vendor literature, undated

T0004

Activated Alumina — General

Abstract
Activated alumina is an ex situ contaminant removal technology that extracts metals from liquid and airstreams by adsorption. It is often used as a polishing treatment in conjunction with

other remediation technologies. Activated alumina technology has been used in remediation of municipal, industrial, and hazardous waste streams for many purposes, including the purification of drinking water, odor control, and as a desiccant, in addition to being used to treat hazardous waste. In site remediation applications, the technology has been used to remove arsenic, selenium, fluoride, and chromium from contaminated groundwater and wastewater. The technology is commercially available through a number of vendors

Activated alumina has the following advantages:

- Allows for versatility in the treatment train (can be used as a filter or as a packed-bed system).
- Allows treated effluent to be discharged into local waste treatment facilities, allowing for a volume reduction of the material that must be disposed as hazardous waste.
- Offers an efficient, simple removal system that can operate without electricity or additional chemicals in some applications.

Activated alumina technology removal efficiency is pH dependent for some contaminants. High levels of competing cations will also reduce process effectiveness. Some studies suggest that the slow diffusion rate of contaminant ions inside the pores of the adsorbent granules makes the technology less economically attractive for some industrial and commercial use. Some studies suggest that arsenite may not be removed by alumina adsorption due to its nonionic character in the process pH range.

Technology Cost

At the Environmental Protection Agency's (EPA's) Perham Arsenic Superfund Site in Perham, Minnesota, a continuous-backwash filtration unit is used to treat groundwater contaminated with arsenic. In 1994, according to the EPA Record of Decision (ROD) at the site, the present worth costs of the remediation were $2,548,776. The annual operations and maintenance (O&M) costs were projected to be $217,805 (D17114C, pp. 2–3).

Some studies suggest that the slow diffusion rate of contaminant ions inside the pores of the adsorbent granules makes the technology less economically attractive for some industrial and commercial use (D17112A, p. 30).

Information Sources

D17112A, ETC, 1995, web page
D17114C, U.S. EPA, undated web page

T0005

Active Environmental Technologies, Inc.

TechXtract

Abstract

TechXtract™ is an extraction technology that has been used to remove a variety of contaminants from the surfaces of concrete, steel, brick, and other materials. Target contaminant types include organics, heavy metals, radionuclides, and polychlorinated biphenyls (PCBs). The technology uses proprietary chemical formulations in successive steps to remove these contaminants. The process employs as many as 25 different components in 3 separate chemical formulations that are applied to the contaminated surface and then removed in a multistep, multicycle sequence. TechXtract is commercially available and has been used at multiple sites.

Some advantages of the technology, as reported by the vendor, include the following:

- Is effective at extracting contaminants that have penetrated below the surface.
- Is effective at removing a variety of contaminant types.
- Does not require specialized equipment.
- Will not damage the surfaces being cleaned.
- Uses process chemicals that are nonexplosive and contain no hazardous products.
- Reduces the volume of waste requiring disposal, which also reduces liability.
- Containerizes liquid waste in drums.
- Minimizes exposure of remediation personnel and others in the project area.

TechXtract has several potential limitations. The technology is limited by the depth it can remove contaminants, which is related to the porousness of the contaminated surface. The technology may be less effective on painted or sealed surfaces. Process chemicals will remove certain types of coatings, but mechanical methods may be needed in some cases. If significant cracks are present in concrete or masonry, pockets of contaminants can form that are not readily extracted. Cracked areas may require sealing, or the area surrounding the crack may have to be chipped out. The environment must have a temperature above 32°F. In addition, the contaminated surface must be accessible to the process chemicals.

Technology Cost

In 1996, the former vendor of TechXtract, EET, Inc., published cost data for two sites, one contaminated with PCBs and another contaminated by radionuclides. Table 1 presents the vendor's comparison of the TechXtract costs to the costs associated with removing the contaminants using scabbling (scarification). Removal costs were based on a 10,000 ft^2 concrete floor with contamination 1 inch deep that requires 99% or greater reduction. Costs for transportation and disposal were based on EET's experiences and information provided by EET's customers. Actual costs will depend on many factors, including surface area, surface type, substrate, contaminant, beginning contamination level, and cleanup criteria (D14280D, p.15).

The TechXtract process was used at a warehouse where PCB contamination resulted from the storage of electrical transformers. The decontamination costs for the concrete floor at this

TABLE 1 Vendor Cost Comparisons for Polychlorinated Biphenyls (PCBs) and Radionuclides (dollars per square foot)[a]

	PCBs		Radionuclides	
	TechXtract	Scabbling	TechXtract	Scabbling
Removal				
First $\frac{1}{8}$ inch	1–2	1–1.5	1.5–2	1.5–2
Next $\frac{7}{8}$ inch	1.5–3	7–10.5	2–4	8–12
Transportation and Disposal				
First $\frac{1}{8}$ inch	0.1–0.15	0.15–0.35	0.25–0.75	1–2.5
Next $\frac{7}{8}$ inch	0.1–0.15	1.05–2.5	0.25–0.75	7–18
Total	2.7–5.3	9.2–12.3	4–7.5	17.5–34.5

Source: Adapted from D14280D, p. 15.

[a] Costs converted from dollars per 10,000 square feet to dollars per square foot.

facility were \$4.60/ft^2. Total costs for the project were just under \$50,000. See Case Study 1 for more details (D140636; D140658, p. 2).

A 200-ft^2 mobile TechXtract processing unit reportedly had an initial capital cost of \$42,000. This unit was capable of processing up to 10,000 lb of contaminated solids per day. Operation and maintenance costs for the unit were \$5 per pound (D19069W).

In 1997, the U.S. Department of Energy (DOE) released bench-scale results of an integrated TechXtract system for decontaminating surfaces contaminated with radionuclides. The overall economics of the system were evaluated. Costs for the system compared favorably with existing options for radioactively contaminated scrap metal (D177859, p. 3).

After a demonstration at the Hanford Site C Reactor in 1998, the DOE estimated that it would cost approximately \$50,000 to remediate the 1956 contaminated lead bricks on site. Costs would range from \$0.96 per pound if the bricks were presurveyed for contamination levels to \$0.99 per pound if the bricks were not presurveyed. The presurveying option is less expensive because not all of the bricks would require decontamination. These estimates do not include money earned from the salvage value of the bricks (D198327, pp.16, 17). The DOE notes that TechXtract was not cost effective at Hanford due to the cheap costs of landfill disposal at the facility (D222719, p. 6).

Information Sources

D14280D, EET, Inc., 1996, vendor information

D140636, Bonem and Borah, 1995

D140658, Bonem, Borah, 1996

D177848, U.S. DOE web page, 1997

D19069W, D&D Technology Module, date unknown

D198327, U.S. Department of Energy, 1998

D222719, U.S. Department of Energy, undated

T0006

ADTECHS Corporation

E-Process

Abstract

ADTECHS Corporation (ADTECHS) has developed the E-Process, a modular system of treatment technologies for processing liquid wastes. According to the vendor, the modules are denoted as “E-P” for the segment of the treatment train that uses an applied magnetic field to dissolve existing carbonate, sulfate, and silica deposits, as well as to destroy bacteria; “E-O” for ozone treatment, which generates ozone to break down organic contaminants; “E-G” for gravity separation, using centrifugal treatment to aid in coagulation and flocculation of particles; “E-C” for an adsorbent phase, using granular activated carbon or some other ion exchange material; and “MRM” for metals removal media. According to the vendor, the technology is patented and commercially available.

The vendor states that the E-Process is a modular system, and only the modules needed for a specific operation are used. If, for example, for microflocculation, the vendor recommends using the E-O (ozone) system, followed by the E-P (applied magnetic field) system, and the E-G (gravity separation) system. Treatment of other waste streams may require different systems or the use of systems in a different order.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0007

ADTECHS Corporation

Radionuclides Separation Process (RASEP)

Abstract
ADTECHS Corporation (ADTECHS) has developed the radionuclides separation (RASEP) process for the removal and stabilization of radionuclides from liquid waste streams. The process uses filtration, selective adsorption, and electrodeposition fixation followed by cement solidification. According to the vendor, the technology is commercially available.

The vendor claims the process is efficient, allows for superior volume reduction, and is cost effective with minimal energy consumption.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0008

ADTECHS Corporation

Wet Oxidation (WetOx) Process

Abstract
The wet oxidation (WetOx) process is used for volume reduction of organic radioactive solid and liquid waste, such as spent bead and powdered resins, filter sludges, and decontaminated waste. According to the vendor, WetOx is effective for the treatment of liquid waste containing organic chelating agents generated by decontamination activities at nuclear facilities. The vendor claims that, through an oxidation reaction with hydrogen peroxide, organic waste and chelating agents are decomposed into carbon dioxide and water. This technology is commercially available.

Advantages of the WetOx process follow:

- Process is fully contained and operates at moderate conditions.
- Process does not lead to the oxidation of nitrogen, or the degradation of sulfuric acid to oxides of sulfur, and no dioxins or furans are produced.
- Process mixture is less corrosive than some other treatment technologies.

The WetOx process can concentrate radioactive contaminants, causing a shift in classification from class A to class B waste. This will have an impact on the selection of solidification media and could effect burial surcharges. The following materials cannot be processed by the WetOx process: spent oil, ammonia, polyvinyl chloride, polyethylene, and rubber.

Technology Cost
No available information.

T0009

Advanced Environmental Services, Inc.

System 64MT Low-Temperature Thermal Desorption

Abstract
The System 64MT low-temperature thermal desorption (LTTD) system is a commercially available ex situ thermal desorption technology. This system uses a countercurrent flow rotary drier to heat soils contaminated with volatile organic compounds (VOCs) to temperatures sufficient to cause contaminants to volatilize and physically separate from the soil. Filter bags remove particulate matter and afterburners/oxidizers are used to destroy organic constituents that remain in the filtered airstream.

The Advanced Environmental Services, Inc. (AESI), soil reclamation facility, American Soil Processing, in Marion, Iowa, includes on-site soil storage capacity and soil processing equipment. The Cedarapids soil remediation system (manufactured by Ratheon Company) used by AESI to treat contaminated soils by low-temperature thermal desorption is similar to that used by another vendor. *See also* Carlo Environmental Technologies, Inc., medium-temperature thermal desorption (T0142).

The process throughput for the thermal desorption system is limited by the British thermal unit (Btu) value of the incoming contaminated soils. Heavily contaminated soils with high Btu content can be damaging to the process. The AESI processing equipment can handle contaminant concentrations approximately 25 to 35% of the lower explosive limit (LEL) in the off-gas stream. High moisture content in the soil decreases processing rates and thus increases processing costs.

Technology Cost
Cost estimates for this technology range from $50 to $125 (1995 dollars) per ton of soil treated. This estimate does not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals.

Factors that have a significant effect on unit price include the following:

- Characteristics of soil
- Quantity of waste
- Utility/fuel rates
- Moisture content of soil
- Initial contaminant concentration
- Characteristics of residual waste
- Waste handling/preprocessing
- Target contaminant concentration
- Amount of debris with waste
- Labor rates
- Site preparation (D10009K, p. 18).

Information Source

D10009K, VISITT Version 4.0, 1995

T0010

Advanced Manufacturing and Development, Inc.

Advanced Bio-Gest System

Abstract
The Advanced Bio-Gest (ABG) is a biologically based, electromechanical system that uses horse manure as its source of microbes. The manure is placed in a stainless steel chamber in

the ABG system and acts as a digestive filter medium. Organic waterborne wastes are pumped and sprayed onto the digesting media. To assure the proper rate of digestion, the system is kept aerobic by passing warm air up through the digesting filter medium. The warm air also picks up moisture and any airborne products from the waste digestion. The moisture-laden warm air next passes through an activated charcoal filter where gaseous products of digestion are adsorbed onto the charcoal. The exhaust air then passes through a condenser where the demineralized water vapor deposits. The water can then be recycled back to factory operation. The remaining air and carbon dioxide are discharged to the atmosphere. The process is self-contained. The system can process approximately 33 gal/day or 1000 gal of wastewater per month and produces 5 or 6 gal of recyclable water per day. The Bio-Gest digesters are designed for bioremediation of organics only; inorganics, especially heavy metals, should be avoided. RIMS was unable to contact the vendor, and thus the commercial availability of this technology is unknown.

Technology Cost

For an ABG system to treat 15 gal of pesticide wastes per day, the capital cost is $14,950 and the average treatment cost is $1.15/gal. The ABG system coupled with a pigment filtration system for treating ink wastes costs $1.98/gal, assuming capital cost is averaged over 5 years (D13970S).

Information Source

D13970S, California Environmental Protection Agency Technology Briefs, 1995

T0011

Advanced Microbial Solutions

SuperBio

Abstract

SuperBio Remediation Treatment is a blend of indigenous microorganisms designed to break down both aromatic and aliphatic carbon-based chemicals either in situ or ex situ. The organisms include *Bacillus, Pseudomonas, Azotobacter, Azospirillum, Rhizobium*, and *Cyanobacteria*. This technology is commercially available. According to the vendor, SuperBio has been used successfully by chemical companies, utilities, and municipalities for cleaning up oil, gasoline, diesel fuel, polychlorinated biphenyls (PCBs), herbicides, and pesticides.

According to the vendor, some benefits to SuperBio are that it:

- Reduces odors.
- Is easy to apply.
- Is cost effective.
- Reduces groundwater and surface water contamination.
- Is nontoxic and nonpathogenic.

All information is from the vendor and has not been independently verified.

Rate-limiting factors for bioremediation can include a lack of sufficient organisms with the metabolic pathways required for degradation. Temperature, oxygen supply, contaminant availability, chemical structure of the contaminant, and soil chemistry can all effect aerobic biodegradation rates. Nutrients such as nitrogen and phosphorous are necessary for biodegradation.

Technology Cost
No available information.

T0012

Advanced Processing Technologies, Inc.

Air-Sparged Hydrocyclone (ASH)

Abstract
The air-sparged hydrocyclone (ASH) is a particle separation technology with a wide range of applications, including the removal and concentration of heavy metals from soil, water, and other media; the removal of oil and oily substances from wastewaters; and volatile organic compound (VOC) stripping from water and sludge. The technology operates on the principles of froth flotation for separation and employs liquid cyclones for collection and removal of contaminants. ASH can remove fine mineral particles that are amenable to froth floatation processes.

According to the vendor, ASH has been used in de-inking flotation for wastepaper recycling, cleaning of waste coal fines, air stripping of VOCs, water disinfection by ozone or chlorine sparging, removal of dispersed oil from water, and heavy-metal removal from old mill tailings. In addition, ASH has been used to treat slaughterhouse wastewater. The technology is commercially available from multiple vendors.

Technology Cost
Because the ASH technology has varied uses in the remediation and industrial sectors, costs will depend on the specific application. According to Advanced Processing Technologies, Inc. (APT), operation and maintenance costs for an ASH system that can process 50 tons of soil per hour are \$2 to \$5 per ton of soil treated. This estimate also includes labor costs. To process a steady feed stream of 10 to 20 gal/min of wash-rack wastewater, operational costs are \$0.60 to \$1.50 per 1000 gal of water treated. The capital costs of an ASH unit for this application range from \$15,000 to \$30,000 (D14439I, p. 2).

An ASH unit used in a U.S. Department of Energy (DOE) test for volume reduction of soil spiked with uranium and plutonium had a total capital cost of \$750,000. The total operating cost of this unit was calculated to be \$8.30 per ton of soil. These estimates were based on a system that could treat 40 to 50 tons of soil per hour (D14800F, p. 43).

The U.S. Air Force tested the effectiveness of ASH at treating emulsified oil, fuel, and grease, as well as aqueous, film-forming foam (AFFF) liquids. These contaminants are common in aircraft wash-rack wastewater and firefighting wastewater. Based on test results, the Air Force determined that ASH can treat contaminated wastewater at a cost of \$0.40 to \$1.10 per 1000 gal (D208219, p. 502).

At Tinker Air Force Base in Oklahoma, potential cost savings of using ASH were estimated to be \$19,125 per year. This estimate was based on a 30-gal/min ASH unit processing 25,000 gal of wastewater per day for 250 days per year. Capital costs associated with installing this unit were estimated to be \$30,000. Overall cost savings were based on the expenses associated with disposing of the wastewater at a municipal treatment plant (D22193C, pp. 2, 6).

Information Sources

D14800F, U.S. DOE, 1995

D14439I, Advanced Processing Technologies, undated

D208219, O’Sullivan and Yi, undated

D22193C, Chirkis et al., 1997

T0013

Advanced Recovery Systems, Inc.

DEACT (Soil Washing)

Abstract

The Advanced Recovery Systems, Inc. (ARS) soil washing technology is an ex situ soil decontamination process for decontaminating radioactively contaminated soil. ARS developed the technology to treat contaminated soil.

The technology treats heavy metals and radioactive metals and is applicable to inorganic chemical manufacturing. A unique feature of the technology is the use of recyclable reagents. The environmentally harmless organic medium used to treat soils contaminated with organic compounds is recovered by distillation. Stronger reagents are recovered either by ion exchange or distillation.

This technology is no longer offered by the vendor.

Technology Cost

The vendor asserts that the ARS system reduces disposal costs by reducing the overall contaminated soil volume, when compared with other disposal methods (D10012F, p. 4).

Information Source

D10012F, VISITT 4.0

T0014

Advanced Recovery Systems, Inc.

DeCaF

Abstract

The Advanced Recovery Systems, Inc. (ARS) developed the patented, ex situ DeCaF™ hydrometallurgical technology to decontaminate fluoride by-products and to recover recyclable metals. The technology uses a proprietary acid mixture to digest the fluoride matrix, freeing radioactive contaminants (e.g., uranium, thorium, or radium) and hazardous contaminants (e.g., lead, arsenic, or chromium). Radioactive elements are recycled or disposed. Metals are also recycled, and fluoride is recovered as a high-value salt for aluminum smelting.

DeCaF treats soil, sludges, solids (e.g., slag), residues, and sediments contaminated with radioactive elements and other hazardous constituents. The technology has potential applications in the treatment of heavy metals. The technology can treat uranium-contaminated calcium fluoride matrices, rare-earth ore residues, and fluorspar contaminated with uranium. The technology can also extract more complex fluoride by-products.

A key feature of the DeCaF technology is the recovery and recycling of reagent chemicals, thereby reducing overall chemical consumption and operating costs.

Technology Cost

According to the vendor, the estimated cost range for using the DeCaF technology ranges from \$200 to \$550 per ton of waste treated. Significant factors that affect the cost include the following (D10010D, p. 28):

- Residual waste characteristics

- Initial contaminant concentration
- Target contaminant concentration
- Soil characteristics
- Waste quantity
- Waste handling/preprocessing
- Debris content of waste
- Utility/fuel rates
- Labor rates
- Moisture content of soil
- Site preparation
- Depth of contamination
- Depth to ground water

Information Source

D10010D, VISITT 4.0

T0015

Advanced Recovery Systems, Inc.

DeHg

Abstract
Nuclear Fuel Services, Inc. (NFS), developed the commercially available DeHg^{SM} process for the low-temperature treatment of mercury-contaminated hazardous and mixed wastes. The technology uses a proprietary amalgamation process to convert mercury into a nonhazardous solid. The technology is now offered by Advanced Recovery Systems, Inc. The developer claims the technology can be used on sludges, hazardous and mixed wastes, and mercury-contaminated wastes containing tritium.

The technology is commercially available.

NFS claims that DeHg technology offers a low-temperature alternative to other mercury recovery processes. They claim that the final waste form generated by processing passes Toxicity Characteristic Leaching Procedure (TCLP) criteria for disposal, and that centrifuge testing has proven that no free liquid mercury remains in the treated product.

Pretreatment is required for DeHg processing. High organic content of process wastes can lead to problems in processing. The process requires modification to treat waste contaminated with chromium.

Technology Cost
According to the vendor, the capital cost of a transportable DeHg system is approximately $100,000. Costs may be lower for some applications (Personal communication: Steve Schutt, Executive Vice President NFS, 1996).

Based on the demonstration of the DeHg process on wastes from the U.S. Department of Energy's (DOE's) Idaho National Engineering and Environmental Laboratory and the East Tennessee Technology Park, the vendor estimated that the costs associated with treating more that 1500 kg of waste contaminated with elemental mercury would be $300/kg. This estimate did not include the disposal costs of the treated wastes (D210480, p. 172).

Researchers used the 1998 demonstration of the DeHg process on wastes from the DOE's Portsmouth Gaseous Diffusion Plant to estimate the unit costs associated with the treatment of soils, sludges, and shreddable debris contaminated with less than 5 wt% of mercury. The estimate included capital, treatment, and decommissioning costs. The cost estimate ranged from \$5.35 to \$6.93/kg of wastes processed at 1000 lb/hr. In a smaller, 100-lb/hr processing plant, the cost estimate rises to a range of \$33 to \$37/kg. Costs increased as the flow rate decreased and as the mercury concentration increased (D20832C, pp. 16, 18).

Information Sources

D20832C, DOE, 1999

D210480, Federal Remediation Technologies Roundtable, 2000

T0016

Advanced Separation Technologies

ISEP Continuous Ion Exchange Resin

Abstract

Advanced Separation Technologies offers the ISEP® ion exchange resin system for the removal of nitrate and perchlorate from contaminated groundwater and wastewater. According to the vendor, the technology can also be used to remove lead, iron, fluoride, chloride, copper, calcium, sulfate, mercury, magnesium, sulfide, and bicarbonate from drinking water. The ISEP resin is designed to concentrate contaminants into a secondary waste stream for disposal or additional treatment. The vendor states that a brine recovery module (BRM) can also be used with the process to destroy contaminants in the secondary waste stream. ISEP has been evaluated in pilot-scale testing for the treatment of contaminated groundwater. It is also patented and commercially available.

According to the vendor, ISEP has the following advantages:

- By concentrating contaminants, the process results in less waste than traditional technologies.
- The system has low capital costs and low operation and maintenance costs.
- The system is more reliable than competing technologies.
- The system achieves maximum removal of targeted contaminants with minimal removal fluctuations.

The ISEP system has the following potential limitations:

- Unless a BRM component is used, the system will not destroy perchlorate; the contaminant is instead concentrated into a form that needs additional treatment or disposal.
- Metals removed by the process will also require subsequent treatment or disposal.
- Organics removal is required prior to treatment.
- Limited data are available on long-term operation.

Technology Cost

According to the vendor, ISEP is less expensive than traditional fixed or pulse-bed treatment technologies (D22289J, p. 2). The vendor estimates that a 1-million-gallon-per-day ISEP system for treating nitrate would cost \$137.44 per million gallons of water treated (D20023N, p. 6). Additional vendor-supplied cost information is summarized in Table 1.

In 1998, Calgon Carbon Corporation prepared an estimate for an integrated treatment system using ISEP technology and another Calgon Carbon system (Rayox®) to remove perchlorate and

TABLE 1 Cost Information for an ISEP Nitrate Removal System

System Specifics	
Treatment rate	1 million gallons per day
Influent nitrate concentration	15 parts per million
Production	364.4 million gallons of water
Secondary waste generated	474,500 gal
Secondary waste generation rate	0.16%
Treated water nitrate concentration	< 1 mg/liter
Resin volume	420 ft^3
System Costs	
Capital costs	$1.4 million[a]
O&M costs per year	$50,000
Chemical costs per year	$26,000
Cost per million gallons	$137.44

Source: Adapted from D20023N.
[a]This cost was associated with a system designed to treat 4.55 million gallons of water per day.

TABLE 2 Cost Information for an Integrated ISEP Rayox System

System Specifics	
Treatment rate	1500 gal/min
Influent nitrate concentration	Perchlorate 18 to 76 parts per billion (ppb), *N*-nitrosodimethylamine (NDMA) not specified
Secondary waste generated	16,200 gal/day
Treated water concentration	Perchlorate <4 ppb, NDMA <0.002 ppb
System Costs	
Unit costs	$1,850,000
Installation costs	$200,000 to $400,000
Operating costs	$570,000
Building costs	$90,000 (1800 ft^2 at $50/$ft^2$)
Waste disposal costs	Not provided

Source: Adapted from D20019R.

N-nitrosodimethylamine (NDMA) from contaminated groundwater in California (D20019R). This cost estimate is summarized in Table 2.

According to a U.S. Environmental Protection Agency (EPA) report, the largest expenses associated with ion exchange technologies like ISEP are disposal costs for the spent-brine solution. Based on a brine rejection rate of 1%, these costs can be over $350 per acre-foot of water treated (D22286G, pp. 1, 2). The vendor states that a BRM has been developed that allows for the on-site destruction of perchlorate, nitrate, and sulfate in the spent-brine solution. This system component could significantly reduce disposal costs (D22287H, p. 1; D22288I, p. 1).

Information Sources

D20019R, Calgon Carbon Corporation, 1998
D20023N, Advanced Separation Technologies, undated
D22286G, U.S. EPA, undated
D22287H, Calgon Carbon Corporation, 2000
D22288I, Venkatesh, 1999
D22289J, D. Environmental, undated

T0017

Advanced Soil Technologies

Thermal Desorption

Abstract

Advanced Soil Technologies (AST) offers the AST thermal desorption system for the treatment of soil contaminated with volatile organic compounds (VOCs). The process heats the soil to remove the targeted contaminants, which are then destroyed in a secondary treatment chamber. The technology has been available commercially. RIMS was unable to contact the vendor.

AST systems cannot process inorganic contaminants or hydrocarbons with boiling points above 900°F. All information used in this summary was provided by the vendor and has not been independently verified.

Technology Cost

In 1995, AST estimated the cost of processing contaminated soil using the AST thermal desorption system would range from $35 to $150 per ton. This estimate stated that price estimates may not include all indirect costs associated with treatment, such as excavation, permits, and treatment of residuals. Factors listed as having a significant effect on costs include (in decreasing order of importance): initial contaminant concentration, moisture content of the soil, the target contaminant concentration, labor rates, characteristics of the soil, utility/fuel rates, site preparation costs, waste handling and preprocessing costs, quantity of waste treated, and the amount of debris associated with the wastes (D10013G, p. 13).

Information Source

D10013G, VISITT 4.0, 1995

T0018

AER Labs

Ensol

Abstract

Ensol is a flocculent and complexing agent that is be used for the ex situ treatment of contaminated aqueous waste streams. According to AER Labs, it works by binding with contaminants, making them precipitate more rapidly and easier to filter out of a waste stream.

The vendor claims that Ensol is applicable for the treatment of wastewaters including sewage after primary treatment, metal plating and finishing waters, and paper mill white water. The claim also extends to the treatment of solid wastes and soils, provided that they contain sufficient free water.

This technology was developed by AER Labs (formerly Ensotech, Inc.) of North Hollywood, California. It has received two patents and is commercially available.

Technology Cost
There is no available information regarding the costs associated with this technology.

T0019

AER Labs

Landtreat Process

Abstract
Landtreat is a silicate-based inorganic polymer catalyst used for the ex situ treatment of contaminated soils. The vendor claims that it acts as a catalyst to degrade halogenated compounds and organic compounds containing nitrogen and sulfur.

The vendor claims that this technology is applicable for the treatment of soils contaminated with a variety of fuels, including gasoline, kerosene, and diesel, as well as alcohols and halogenated solvents. However, field tests by the state of California's Department of Toxic Substances Control showed no statistically significant improvement for use of Landtreat versus a similarly watered and aerated control plot.

This technology has been used in at least one full-scale application. Landtreat is a patented technology and is commercially available.

Technology Cost
A cost estimate was produced by the California Environmental Protection Agency (C-EPA) following a full-scale demonstration by AER Labs (formerly know as Ensotech, Inc.). The C-EPA estimated that treatment costs range from \$70 to \$130/yd^3 of soil treated. Factors that determine the cost of treatment include the concentration of contaminants and the scale of the project (D16271K, p.7).

Information Source

D16271K, California Environmental Protection Agency, 1990

T0020

Aeration Basins — General

Abstract
Aeration basins are wastewater ponds or lagoons that have air introduced by mechanical action. Aeration may be performed to assist aerobic bioremediation and/or to remove volatile organic compounds. In an aeration basin, oxygen is usually supplied by surface aerators or by diffused aeration units. The action of the aerators and that of the rising air bubbles from the diffuser is used to keep the contents of the basin in suspension. Aeration is widely used in wastewater treatment and can be adapted to treat groundwater.

Technology Cost
No available information.

T0021

Aeromix Systems, Incorporated

BREEZE

Abstract

The Aeromix BREEZE™ is an air stripping system for removal of ex situ volatile organic compounds (VOCs) from aqueous waste streams. The BREEZE is commercially available and has been used in numerous remediations.

The Aeromix BREEZE air stripping system is a transportable system designed with an aeration tank coupled with a blower. The aeration tank incorporates CYCLONE nonfouling, all stainless steel air diffusers that provide the air-to-water interface needed for stripping and contaminant removal.

All information was provided by the vendor and has not been independently verified. This technology does not treat metals.

Technology Costs

No available information.

T0022

Aero-Terra-Aqua, Technologies Corp

Aqua-Fix

Abstract

The Aqua-Fix® technology utilizes patented polymeric beads containing nonliving biomass immobilized in sodium silicate or polysulfone binder to remove heavy metals from aqueous solutions. The beads have the ability to sorb metals from aqueous waste streams. They are especially effective at low metal concentrations where federal regulations require discharged effluents to contain less than 1 mg/liter. The technology may be used for industrial pretreatment, potable pretreatment, groundwater remediation, storm water treatment, acid mine drainage, and landfill leachate.

The vendor claims that the following metals have been successfully treated to parts per billion (ppb) and detection limit levels: aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, tin, uranium, vanadium, and zinc. The system is also able to remove ammonia, nitrates, phosphates, potassium, fluorides, and sodium. Studies have also been performed using Aqua-Fix to remove radionuclides such as uranium from waste streams.

Aqua-Fix is a commercially available technology. Existing process delivery operations such as tanks, columns, or canisters can be used with the Aqua-Fix technology. Custom-engineered treatment systems are also available. The beads used in the system can be used several times. Saturated beads are immersed in dilute mineral acid to extract sorbed metals. According to the vendor, beads can be used after 20 regenerations while maintaining a near-100% loading capacity.

Technology Cost

Based on 1 year of operation and regeneration, the vendor claims that smaller applications typically cost \$0.01 per liter. For larger applications, the price may fall to \$0.0005/liter. The vendor claims that the projected cost to remove zinc from a wastewater stream is \$0.01/liter (D14689Y, p. 1).

A feasibility test is conducted to ensure that constituents that would inhibit the Aqua-Fix absorption capabilities do not exist in the water. This test, including characterization, testing, and a report is $275.00 per contaminant. Two hundred dollars of the cost can be credited toward an order of $1000.00 or more if placed within 60 days of the issuance of the report (D14690R, p. 4).

Information Sources

D14690R, Aero-Terra-Aqua Technologies, 1996
D14689Y, Aero-Terra-Aqua Technologies, 1996

T0023

Affinity Water Technologies

Advanced Affinity Chromatography

Abstract
Advanced affinity chromatography (AAC) media are used for the adsorption of metals from ground and waste waters. The AAC technology has been used in multiple applications and is commercially available from Affinity Water Technologies, formerly Ntec Solutions, Inc.

In AAC technologies, water is exposed to an AAC material, and metals in the water are adsorbed by the material. AAC systems can be designed and built as stand-alone units or integrated to work efficiently in concert with complementary water treatment systems designed for hydrocarbon removal, pH control, particulate removal, or electrodialysis. AAC systems can tolerate hard water (calcium and magnesium) and high temperatures (up to 200°F) without a decrease in performance.

None of the vendor claims was able to be supported or refuted by any third-party data. The technology does not treat organic compounds.

Technology Cost
No available information.

T0024

Air Stripping — General

Abstract
Air strippers are ex situ devices used to physically transfer volatile organic contaminants (VOCs) from groundwater, surface water, or wastewater to air. Contaminants are not destroyed by air stripping, but once they are transferred to the airstream, they may be destroyed by oxidation or incineration, or removed using activated carbon absorption.

There are many commercially available air stripper technologies. There are several different types of air strippers, including packed towers, tray-type, spray aerators, mist aerators, diffused aerators, low-profile packed towers, and centrifugal air strippers. According to the U.S. Environmental Protection Agency (EPA), an estimated 1000 air stripping units were operational at sites throughout the United States in 1991 (see Table 1).

There are several advantages to air stripping systems:

- Used in industry for many years
- Applicable to a wide variety of VOCs and certain semivolatile organic contaminants (SVOCs) under specific conditions

TABLE 1 Additional Air Stripping Site Data[a]

Location/Date	Contaminants	Amount of Contaminated Media Treated	Unit Cost of Treatment	Reference
Keefe Environmental Services Superfund Site, Epping, NH, 1993–1997	Chlorinated solvents TCE; PCE; benzene; 1,1-DCE; and 1,2-DCA	46 million gallons through May, 1997	$52/gal of groundwater treated, $35,000/lb of contaminants removed	D19692D
Intersil, Inc., Site, Sunnyvale, CA, 1987–1995	TCE; 1,2-DCE; vinyl chloride; Freon-113	36 million gallons[b]	$38/gal of groundwater treated, $108,900/kg of contaminants removed	D19683C
Twin Cities Army Ammunition Plant, New Brighton, MN, 1987–1992	TCE; 1,1-DCE; 1,1-DCA; PCE; 1,2-DCE; chloroform; 1,1,1-TCA	Through 1992, 92,700 lb of VOCs removed	N/A	D19321P
Lawrence Livermore National Laboratory, Livermore Site, Livermore, CA, 1989–Date	TCE; PCE; 1,1-DCE; 1,2-DCE; 1,1-DCA; 1,2-DCA; carbon tetrachloride; chloroform; BTEX	NA	N/A	D19320O
LaSalle Electrical Superfund Site, LaSalle, IL, 1992–Date	PCBs[c]; PCE; TCE; trans 1,2-DCE; 1,1,1-TCA; 1,1-DCA; vinyl chloride	23,233,000 gal through 9/97	$266 per 1000 gal of groundwater treated $48,000/lb of contaminants removed	D19673A

[a] Abbreviations: dichloroethene (DCE); trichloroethylene (TCE); perchloroethylene (PCE); trichloroethane (TCA); benzene, toluene, ethylbenzene, and xylene (BTEX); polychlorinated biphenyls (PCBs).
[b] Pump-and-treat system only.
[c] Air stripping system did not treat PCBs.

- Minimal energy costs, compared with thermal treatment technologies
- System can be designed for site-specific treatment goals

Air stripping technology is ineffective for treating low-volatility organic contaminants, metals, or inorganics. Aqueous solutions with high turbidity or elevated levels of iron, manganese, or carbonate may reduce removal efficiencies due to scaling and the resulting channeling effects.

Influent streams with pHs greater than 11 or less than 5 may corrode system components. Biological fouling may also occur.

Influent streams with contaminant concentrations greater than 0.01% generally cannot be treated by air stripping. Even at lower influent concentrations, air strippers may not be able to meet cleanup goals. Typically, some air pollution control technology is required to capture or destroy contaminants in the off-gas stream or the treated effluent.

Technology Cost

Cost of an air stripping system is site specific and contaminant specific. In 1991, the cost of air stripping contaminants with a Henry's law coefficient from 0.1 to 10 was estimated to range from \$0.07 per 1000 gal of water treated to \$0.70 per 1000 gal of water treated (packed-tower system). As the Henry's law coefficient was decreased to 0.005, costs rapidly rose to \$7.00 per 1000 gal of water treated (D16424J, p. 7).

Factors that impact the cost of an air stripping system include system design, emission controls, effluent treatment (if required), and operations and maintenance. The addition of an air treatment system roughly doubles the cost of an air stripping system (D16424J, p. 7).

In 1993, it was estimated that low-profile air strippers cost between \$4000 and \$40,000 and have treatment capacities ranging from 1 to 360 gal/min (gpm). Packed-tower air strippers have capacities ranging from 5 to 10,000 gpm and cost from \$2000 to \$200,000 (D15445K, p. 28).

Cost information from Case Studies 1 and 3 is summarized below:

Case Study 1. Pump-and-Treat System with a Packed-Tower Air Stripper, McClellan Air Force Base Superfund Site, California, Operable Units B/C, 1987. The costs associated with pump-and-treat system used at the site were estimated in 1994. Costs were approximately \$80 per pound of removed volatile organic compounds (VOCs) based on operating costs alone and approximately \$150 per pound when capital costs were included (D141286, p. 135). It should be noted that the operation and maintenance costs for the an air stripper could not be separated from the total cost of the project. Capital cost and operating cost information for this project are summarized in Case Study 1.

Case Study 3. Fort Drum National Guard Station, Fuel Dispensing Area, Watertown, New York. Total capital costs of the system were \$958,780. System design costs were based on a contractor's 95% design estimate prepared in 1991. Construction costs were based on a contractor's cost proposal. Operating costs of the system were estimated to be \$129,440 per year. This estimate was based on a contractor's scope of work for operation and maintenance of the interim pump-and-treat system, dated September 1993. The estimate includes carbon changeout, transport, and regeneration; electrical power; equipment repair and replacement; laboratory analysis; operation and maintenance (O & M) labor; engineering support; and project management (D141253, p. 70). The details of the capital cost estimate are included in Case Study 3.

Information Sources

D15445K, Lamarre, 1993
D141253, U.S. EPA, 1995
D141286, U.S. EPA, 1995
D16424J, U.S. EPA, 1991
D19678F, U.S. EPA, 1998
D19270V, U.S. DOE, 1999
D19692D, U.S. EPA, 1998
D19683C, U.S. EPA, 1998
D19321P, U.S. DOE, undated

D19320O, U.S. DOE, undated
D19673A, U.S. EPA, 1998

T0025

Akzo Nobel Macro Porous Polymer Systems

Macro Porous Polymer System

Abstract
The Macro porous polymer (MPP) system is an ex situ technology designed to remove hydrocarbon pollutants from process water, groundwater, and wastewater. This technology uses a patented, porous polymer containing an immobilized extraction fluid that assimilates the hydrocarbons into the polymer structure. The particles are regenerated with an in situ heating cycle, and the contaminants are recovered for reuse, recycle, or disposal.

According to the vendor, this technology is capable of removing chlorinated hydrocarbons, aliphatic hydrocarbons, aromatics, benzene, toluene, xylene, carbon tetrachloride, vinyl chloride, dichloromethane, and trichloroethane. Polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), and volatile inorganic solvents can also be removed. The technology is currently in use and is commercially available.

According to the vendor, the technology offers the following advantages:

- Achieves low effluent concentrations.
- Allows in situ media regeneration.
- Combines two reliable technologies (steam stripping and extraction).
- Allows for automation, minimizing operating requirements.
- Recovers hydrocarbons for reuse or recycling.
- Has a compact design and a small footprint.
- Consumes less steam than conventional steam stripping technology.
- Allows for other possible treatment steps.

MPP extraction (MPPE) technology is applicable to aqueous waste streams contaminated with compounds with a higher affinity for the extraction liquid than for water. Water-miscible compounds such as alcohols and ketones have low affinities for the immobilized extraction

TABLE 1 Cost and Other Parameters for Macro Porous Polymer System Technology

Site	Flow Rate[a]	Feed Conc.[b]	Effluent Conc.[c]	Investment in Dollars	Steam Usage (tons/year)	Power Usage[d]	Service Contract in Dollars/Year
a	15	2,000	10.0	$220,000	170	16,000	25,000
b	15	2,000	0.1	$240,000	290	17,000	38,000
c	15	3,000	0.1	$245,000	300	17,000	40,000
d	22.5	2,000	0.1	$255,000	390	17,500	47,000

Source: Adapted from D18247S.
[a] Flow rate is in gallons per minute.
[b] Feed concentration is in parts per million (ppm).
[c] Effluent concentration is in ppm.
[d] Power usage is in kilowatt-hours per year.

liquid and are only partially removed from water with the MPPE units. The MPPE technology removes and extracts contaminants with high volatiles and boiling points up to 250°C.

Technology Cost
In 1998, the vendor released cost information based on case studies of Macro Porous Polymer System technology (D18247S, p. 79). This information is presented in Table 1.

Information Source

D18247S, van der Meer and Brooks, 1998

T0026

Alliance Bioremediation and Composting Corporation

Vermiculture

Abstract
Vermiculture is an ex situ technology that uses earthworms to biodegrade organic wastes.

This technology can be used as an alternative to other means of treatment or disposal of animal wastes or food processing wastes.

This technology is in use and is commercially available from Alliance Bioremediation and Composting Corporation.

Technology Cost
There is no available information regarding the costs associated with this technology.

T0027

AlliedSignal Environmental Systems and Services, Inc.

Biological Air Treatment (BAT) System

Abstract
The AlliedSignal biological air treatment (BAT) system is a fixed-film biological reactor designed primarily to remove volatile organic compounds (VOCs) from a continuous vapor stream. It can be applied to any air or vapor exhaust system that contains biodegradable organic contaminants, including aromatic hydrocarbons such as BTEX (benzene, toluene, ethyl benzene, and xylene) and naphthalene and biodegradable chlorinated organics such as trichloroethene (TCE). The BAT system is being used commercially to treat exhaust gases from several creosote wood preserving operations. Other applications include use with soil vapor extraction systems, commercial bakeries, pharmaceutical plants, food processing plants, and chemical plants.

The BAT system operates based on principles of aerobic cometabolism. In cometabolism, enzymes that the microbes produce in the process of consuming one particular compound (e.g., phenol) have the collateral effect of transforming another compound that normally resists biodegradation (e.g., chlorinated ethenes, especially lesser chlorinated ethenes such as dichloroethene or vinyl chloride). The BAT system operates under these principles by sorbing the chlorinated compounds from a vapor stream onto powdered activated carbon (PAC) where they are cometabolically transformed into a combination of end products, including new biomass, carbon dioxide, inorganic salts, and various acids.

A biomass (microorganisms used for reduction of contaminants) support matrix is used, consisting of porous polyurethane foam with a surface area greater than 200 ft^2/ft^3 (670 m^2/m^3).

This support matrix is coated with PAC using a proprietary procedure that maintains the carbon in an activated state. Use of this porous polyurethane foam overcomes a difficulty that technology developers have had in identifying materials that are suitable support for the biomass when used to remove organic pollutants from the vapor phase.

The system cannot handle large concentrations of contaminants because overload occurs and steady-state development and operation of the microbial culture is not achieved.

Technology Cost
No available information.

T0028

Alternative Biowaste Elimination Technologies, LTD (ABET)

WR^2

Abstract
According to Alternative Biowaste Elimination Technologies, LTD (ABET), the WR^{2TM} technology is a novel process that uses alkaline hydrolysis to liquify or dispose of biological waste (animal tissue) from research and clinical facilities.

ABET claims that the WR^2 technology is used primarily for the disposal of animal carcasses and other biological tissues. The developer also claims that the technology can be used to dispose of human tissues from surgery, pathology, obstetrics, and gynecological practices.

The developer asserts that the technology is a cost-effective means of disposing of biological tissue contaminated with radioisotopes, infectious agents, glutaraldehyde, embalming fluids (i.e., formaldehyde, phenol, and glycerine), and biological components of regulated medical waste.

ABET believes that the technology has applications in medical centers, veterinary schools, pharmaceutical companies, and state and federal governmental research and testing agencies.

According to the developer, the WR^2 process has the following advantages:

- Decomposes certain hazardous wastes at no additional cost.
- Eliminates the need to transport biological materials off-site for disposal.
- Reduces the volume and weight of the waste material by more than 97%.
- Reduces handling of carcasses contaminated with infectious agents, radionuclides, etc.

As per information from the vendor received in September 1999, the company is closed for business and WR^2 is no longer available.

Technology Cost
Alternative Biowaste Elimination Technologies, LTD (ABET) claims that during three years of operation in the WR^2 Development Laboratory at the Albany Medical College, the WR^2 100-gal prototype unit processed more than 15 tons of animal carcasses at a cost of less than \$0.06 per pound. The developer claims that the cost shows a greater reduction with larger units (D16459U, p. 3). Additionally, the medical center processed the animal carcasses at a reagent cost of less than \$1800 (D16458T, p. 21).

Information Sources

D16459U, Alternative Biowaste Elimination Technologies, LTD, May 9, 1997

D16458T, Signorelli and Leveston, 1997

T0029

Alternative Technologies for Waste, Inc.

Detoxifier In Situ Steam/Hot-Air Stripping Unit

Abstract
The Detoxifier™ in situ steam/hot-air stripping unit is a mobile technology designed to remove volatile and semivolatile organic compounds (VOCs and SVOCs) from contaminated soil. The unit strips these from the soil via a dual auger system, which injects steam and hot air into the mixing soil and collects/concentrates the off-gases for recycling or disposal.

The Detoxifier is used to remove VOCs from a variety of soil types and has been used successfully at several sites. It has limited applicability for SVOCs because of their higher boiling points and does not function as well in soils with a high clay content.

Technology Cost
The in situ steam/hot-air Detoxifier is competitively priced and would be a good alternative for sites that require short treatment times. The cost is directly proportional to the time spent on each unit of soil treated, so treating soils with high clay content or treating shallow spills might be economically prohibitive because VOCs bind with clayey soils and require longer treatment times and because shallow soil treatments require moving the Detoxifier unit frequently.

Cost estimates are based on treating 8925 yd^3 (6820 m^3) over 266 days of treatment, using the company's commercial prototype. A site demonstration estimated the cost for treatment to be from \$111 to \$317/yd^3 (\$145 to \$415/m^3), based on 70% online factor at 10 to 3 yd^3/h, respectively (D12487I, p. 6). Because the process is so labor intensive, the cost declines as the online factor rises and as treatment time per yard falls.

Approximately 47% of the costs associated with operating this technology are for labor, and the bulk of the remainder derives from purchasing the \$2 million Detoxifier unit (D104654, pp.19–20). It should be kept in mind that these estimates are in 1991 dollars and that the machine used was a company prototype.

Information Sources

D12487I, de Percin, 1991
D104654, U.S. EPA, 1991

T0030

Alternative Technologies for Waste, Inc. (ATW)

TerraSURE

Abstract
The TerraSURE™ apparatus removes soil (to a depth of 30 ft), adds an optional impermeable liner and/or process piping, and then redeposits the soil on top of the liner—all in a continuous process. TerraSURE technology is a mobile system that can operate as a stand-alone containment system, or as part of a treatment train, or to introduce amendments for bioremediation or stabilization. The unit typically installs impermeable barriers at the base and sides of the site, and generally applies a cap to the site during processing. The resulting pit (with or without the optional lining or piping) is referred to by the technology developer as a "In Situ Process Reactor." The technology is patented, commercially available, and available for licensing.

The vendor claims the following advantages of TerraSURE technology:

- Faster and more cost effective than conventional technologies
- Faster processing of contaminated soil
- Adaptable to many remediation approaches
- Reduces personnel health and safety risks

Technology Cost
No available information.

T0031

Altex Technologies Corporation

BioBinder Activated Carbon (BAC)

Abstract
BioBinder activated carbon (BAC) is being developed for recovering metals from waste streams. The technology is in the early testing stages of development and, as such, is not commercially available.

Activated carbon (AC) is carbon that has been heated to high temperatures to develop a porous structure. The interior of these pores provides a considerable surface area onto which metals can be adsorbed. The extent to which AC can remove metals is a function of the amount of AC as well as porosity and surface chemistry.

BAC has been formulated to minimize the cost of adsorbent by using waste as its starter material. BAC is made from a mixture of approximately 85% waste coal fines and 15% municipal sewage sludge on a dry basis. Both materials have very low or no cost and have attributes that contribute to good pore development.

According to the vendor, the use of wastes to produce BAC will decrease the amount of waste that must be disposed of. If BAC were used to replace only 10% of conventional AC, some 50,000 tons of BAC would be needed per year. Approximately 78% of the solids are consumed in the process; thus more than 200,000 tons of waste are beneficially used each year by applying BAC.

Technology Cost
Due to this technology's stage of development, no cost information is available regarding product cost. Cost information regarding production cost, however, has been developed. The cost of producing BAC is 39% less than producing conventional activated carbon: $227.00 per ton for BioBinder pellets compared with $375.00 per ton for activated carbon pellets made from wood char and wood tar in 1996 dollars (D13742I, p. 2).

Information Sources

D13742I, Vendor information

T0032

Alzeta Corporation

EDGE Thermal Processing Units (TPUs)

Abstract
Alzeta Corporation (Alzeta) has developed the EDGE thermal processing units (TPUs) for the treatment of volatile organic compounds (VOCs). The technology was originally developed as

a method of abating VOCs in industrial processes, and is now commercially available for the remediation of soils containing halogenated chemicals. The vendor states that the technology effectively destroys both chlorinated and fluorinated chemical vapors and is designed to prevent the formation of dioxins and furans. The EDGE systems are based on proprietary and patented technology.

Alzeta states that their TPUs can achieve 99.99% destruction with emissions of nitrogen oxides and carbon monoxide of <10 parts per million (ppm) corrected for 3% oxygen emissions. They also state the Alzeta systems prevent the formation of dioxins and furans, and are available with several different operating systems and capacities for different site requirements.

According to the vendor, the EDGE TPUs have several advantages:

- Accepts wide variations in contaminant concentrations.
- Offers installation and design flexibility.
- Operates cost effectively and reliably.
- Minimizes the formation of dioxins and furans.

Technology Cost

In 1995, SEMATECH performed an evaluation of the Alzeta TPU for abating perfluorocompounds (PFCs). Based on this evaluation, a cost estimate was performed. While the costs of a commercial-scale remediation system may vary from this estimate, the information is discussed as a basis for comparison.

The TPU equipment cost was $45,000 with an additional charge of $18,000 for consultation after the initial installation. SEMATECH stated that the consulting fee would probably not be necessary for a commercial unit. Installation costs of $51,080 included gas lines, water lines, wastewater sump, booster pumps, a water meter, rotameters, alarms, etc. This cost also included the facilitation of the screening and modeling test equipment, the facilities water system, and all engineering and technician labor required. It was assumed that installation costs would be significantly lower for a commercial unit (approximately $20,000) (D17789D, pp. 44).

The vendor recommended that at least $6100 worth of spare parts be maintained in stock. Some of these items included: TPU-116 liner, single pack (burner, air inlet filter assembly, packed-tower filling material, and a hydraulic hose-packed tower water supply). During the 3-month trial, $4510 worth of replacement parts were used. These replacement parts were a

TABLE 1 Utility Costs of Industrial Thermal Processing Unit Based on a 3-Month (2078-h) Operational Period

Utility	Consumption Rate	Unit Cost in Dollars	Total Cost
Nitrogen gas	20 standard cubic feet/hour (scfh)	0.0012/cf	$50
City water	8 gal/min	0.00265/gal	$2643
Industrial wastewater	8 gal/min	0.00385/gal	$3840
Natural gas burner	100 scfh	0.012/cf	$2494
Natural gas injection	8 scfh	0.012/cf	$12
Scrubbed acid exhaust	40 standard cubic feet/minute (scfm)	0.0000025/cf	$12
Cabinet exhaust	100 scfm	0.000001/cf	$12
Electrical	1.6 kwh	0.06/kW	$200
Air conditioning load	1000 Btu/h	0.000009/Btu	$18
Total utility cost for 2078 h of operation			$9281
Projected utility cost for 1 year at 83% tool utilization			$332,474

Source: Adapted from D17789D.

TPU-116 liner, single pack (burner), an ultraviolet flame scanner, a TPU sump pump, a scrubber demister pad, inlet water filters, and an inlet recirculation valve (D17789D, p. 40).

SEMATECH estimated that the 5-year cost of operation for the prototype unit abating four-chamber exhausts containing PFCs was $83,000/ year based on an 83% TPU operation; while the commercial TPU cost of operation was $77,000/ year based on 100% TPU operation. The scrubber's once-through waster usage of 8 gal/min represents the major utility cost. It was assumed that a commercial facility would have lower electrical costs by eliminating the booster pump and extra sump pump (D17789D, pp. 9, 44). Table 1 discusses the annual utility costs associated with the industrial unit.

Information Source

D17789D, Gilliland et al., 1995

T0033

Ambient Engineering, Inc.

BIOTON

Abstract

The BIOTON technology biologically degrades volatile organic compounds (VOCs) from contaminated off-gases. BIOTON was developed in the Netherlands by ClairTech N.V. Ambient Engineering, Inc., is the licensee for the northeastern United States, and the technology is also available from Enviro-Chem Systems, Inc.

Biofiltration is typically used to reduce hazardous air pollutants for regulatory compliance or odor control. According to vendor literature, this technology is designed to treat gas streams with dilute concentrations of 1,500 parts per million (ppm) or less. There are over 75 BIOTON installations operating worldwide including KODAK, Fuji Photo, Mercedes Benz, Coca-Cola, and Union Camp.

All information is from the vendors and has not been independently verified.

Technology Cost

In 1996, costs for three popular air treatment technologies, including biofiltration, were compared in a trade magazine where the analysis assumed a 4000 ft^3/min airstream containing organic contaminants typically found in the printing industry. Biofiltration was compared with regenerative thermal oxidation and recuperative catalytic oxidation. Although installation cost for the biofilter was more expensive than for the regenerative thermal oxidizer, lower operating costs favored biofiltration after 5 years of operation (D16218F). The article cautioned that pilot studies may be needed to establish design criteria for individual installations, particularly for compounds or gas streams that have not been tested previously.

Information Source

D16218F, Environmental Technology, 1996

T0034

American Biotherm, L.L.C

Biotherm Process (Second-Generation Carver Greenfield Process)

Abstract

The Biotherm Process™ is an improved second-generation version of the patented Carver Greenfield Process® (C-G process). The Biotherm Process™ is designed specifically for drying and detoxifying municipal sewage treatment solids.

The Biotherm Process uses the patented C-G Process approach for drying and solvent extraction to separate oil-soluble contaminants from liquid, solid, or slurry wastes. The C-G Process has been used extensively over the last 30 years to dry and extract compounds from a variety of wet, oily solids (D105453, pp. 1, 23). The C-G Process has been evaluated on the demonstration level by the U. S. Environmental Protection Agency (EPA) for treating petroleum-contaminated drilling mud from a Superfund site.

Although the C-G Process has been proven in over 80 installations worldwide, the municipal sludge drying plants based on the C-G Process that were constructed in the late 1980s included some design features that led to serious operations problems. Learning from the experiences of the first-generation C-G plants, the Biotherm Process depends on proven process concepts, eliminating the features that have led to the major operating problems in the past.

There are several advantages of the Biotherm Process for application to municipal sewage sludge drying. According to the vendor, the Biotherm Process can handle feed sources with widely varying composition and is much more energy efficient than conventional steam driers. Because the drying is accomplished under mild conditions, thermal decomposition of the solids is avoided, and vent gas cleanup problems are minimal. Conditions are sufficient to destroy bacteria, viruses, and other pathogens. *See also* Dehydro-Tech Corporation, The Carver Greenfield® Process (T0199).

The Biotherm Process does not destroy wastes; it rather separates mixtures into streams that can be used more safely, disposed of, or treated. The process does not treat metals. Solids with high percentages of insoluble metals may require special management or additional treatment prior to disposal.

Privatized Biotherm Process plants (i.e., plants developed on a "build, own, and operate" basis by American Biotherm, L.L.C.) to dry municipal sewage sludge are being developed. The Dehydro-Tech Corporation, the developer of the Carver Greenfield Process, became American Biotherm, L.L.C., in late December 1996. American Biotherm, L.L.C. now commercially offers the Biotherm Process.

Technology Cost

According to the vendor, the Biotherm Process technology is much more energy efficient than steam driers.

Specific cost information for application of the Biotherm Process technology for drying municipal sewage sludge is not available.

Privatized Biotherm Process plants (i.e., plants developed on a "build, own, and operate" basis by American Biotherm, L.L.C.) to dry municipal sewage sludge are being developed. According to American Biotherm, L.L.C., large regional plants, built, owned, and operated by the American Biotherm Team offer municipalities an economical option for sewage sludge disposal (D11044R, p. 5).

See also Dehydro-Tech Corporation, The Carver Greenfield Process (T0199).

T0035

American Combustion, Inc.

Pyretron Thermal Destruction System

Abstract

The Pyretron thermal destruction technology is a burner system designed to be used in conjunction with any conventional transportable or fixed rotary kiln incinerator and is intended to increase the efficiency of conventional incineration. The commercially available technology controls the heat input during incineration by controlling excess oxygen available to oxidize hazardous waste.

The Pyretron technology can be used to treat any waste amenable to treatment via conventional incineration. Its primary advantage, increased throughput, can best be realized in the treatment of solid wastes with relatively low heating value. This is because the major factor limiting throughput for low heating value wastes is the volume of combustion gas required for incineration of a unit volume of waste. Since oxygen enhancement reduces combustion volume by displacing diluent nitrogen in the combustion airstream, it significantly reduces the volume of combustion gas required, thus allowing throughput increases for this type of waste.

The technology is not suitable for processing Resource Conservation and Recovery Act (RCRA) heavy-metal wastes or inorganic wastes. In addition, various problems were identified during the U.S. Environmental Protection Agency's (EPA's) evaluation of the technology. First, a process controller increases the oxygen level to preset levels in response to varying carbon monoxide or oxygen levels. According to the EPA, the initial and final levels of oxygen fed to the system were the same regardless of whether the stimulus was an elapsed time of 30 sec since the initiation of a batch feed cycle or a carbon monoxide spike. Thus there was some uncertainty to what extent the process controller reacted to conditions within the incinerator. Further, these levels were preset by the operator prior to the initiation of incineration and were based on the operator's judgment, which in turn is based on some prior knowledge about the way in which a given waste stream is likely to ignite and burn in the incinerator. Second, high heating value wastes were difficult to incinerate at elevated feed rates with oxygen enhancement since oxygen displaces nitrogen. Thus nitrogen is not present to act as a heat sink, and the practical heat release limitations of the incinerator are soon reached. Third, nitrate levels produced by the Pyretron were elevated over those that occurred without oxygen enhancement and resulted from the high flame temperatures produced when the Pyretron is used with oxygen enhancement. Air-only operation resulted in average nitrate levels of 92 parts per million (ppm) while use of Pyretron with oxygen enhancement resulted in average nitrate levels of 1073 ppm.

Technology Cost

American Combustion, Inc.'s (ACI), Pyretron Thermal Destruction technology is not a standalone technology and employing it is a matter of retrofitting it to, or installing it on, a conventional incinerator. The EPA's economic analysis focuses on estimating the incremental costs and benefits that are likely to arise from adding a Pyretron burner to an existing incinerator. A conventional incinerator has an hourly throughput, when operating at 100% utilization, of 0.7 ton/hr. An incinerator retrofitted with a Pyretron burner, which has the potential to double throughput, would treat 1.4 tons an hour at 100% utilization. Because 100% utilization is unlikely, the utilization rate is 80% for the conventional incinerator and 75% for the addition of the Pyretron (difference in utilization rate is due to additional downtime of the Pyretron unit compared to the incinerator by itself). At the adjusted utilization rates, the yearly throughput for the conventional incinerator is 4906 tons per year. The yearly throughput increases to 9198 tons/year with the Pyretron unit attached (D13940M, p. 13–14).

The increase in throughput achieved when using the Pyretron system will reduce the amount of time the incinerator operator is on site. The EPA cost estimate, in 1989 dollars, assumes a total of 4930 tons of contaminated soil to be treated. The conventional incinerator would be on the job site for 367 24-hour days to process the waste while the Pyretron would be on site for 196 24-hour days. Table 1 shows the daily labor cost, highlighting labor rates, hours worked, and per diem. Based on the daily labor cost of $3825, the total project labor cost using a conventional incineration would be $1,404,068. Using the utilization rates described above, the installation of the Pyretron system would reduce the number of operating days, which in turn would reduce the total project labor costs to $749,856. This results in a savings of $654,211 and an incremental benefit due to labor savings of $132 (D13940M, p. 16).

For a conventional incinerator the fuel consumption rate is 7.41 MW resulting in a $102.93 an hour cost for fuel. With an adjusted hourly throughput, the resulting fuel cost is $183.80 per treated ton. The corresponding consumption rate for the Pyretron system is 6.36 MW resulting

TABLE 1 Daily Labor Rate Calculation for 24 hr a Day Operation of Pyretron Thermal Destruction

Shift	Job Title[a]	No.	Hour/ Day	Wage Rate ($)[b]	Daily Wage ($)	Per Diem ($)	Daily Total ($)
Day	SE	1	8	46.00	368.00	75	443.00
	O	1	8	30.00	240.00	75	315.00
	A	1	8	17.00	136.00	75	211.00
	MH	5	40	15.00	600.00	0	600.00
Swing[a]	O	1	8	33.00	264.00	75	339.00
	A	1	8	18.70	149.60	75	224.00
	MH	5	40	16.50	660.00	0	660.00
Night[c]	O	1	8	36.00	288.00	75	363.00
	A	1	8	20.40	163.20	75	238.00
	MH	3	24	18.00	432.00	0	432.00
Total $3825.80							

Source: D13940M, U.S. EPA, 1989.
[a] SE = senior engineer, O = operator, A = asst. operator, MH = material handler.
[b] The wage rate is a loaded rate that assumes a multiplier of 2 on worker salary to account for fringe benefits, administration costs, and profit.
[c] The swing and night shifts reflect a 10 and 20% differential, respectively.

in an $88.35 an hour cost for fuel. With an adjusted hourly throughput, the resulting fuel cost is $84.15 per treated ton of waste. This results in an incremental benefit due to fuel saving of $99.65 per ton (D13940M, p. 16).

The oxygen cost for the Pyretron incinerator is $232.50 per hour of operation. At the adjusted throughput rate of 1.05 tons per hour, this converts to an oxygen cost of $221.43 tons per hour. Since the conventional incinerator uses no oxygen, this cost is considered an incremental cost. Water injection cost for the Pyretron system remain at $0.90 per ton. A royalty fee is also charge by ACI at a flat rate of $7.50 per ton of waste treated. This is an incremental cost for the Pyretron system (D13940M, p. 16–17).

Table 2 summarizes the incremental treatment savings and costs projected for the Pyretron system under the assumptions presented above compared to the vendor-supplied cost data, which

TABLE 2 Summary of Incremental Savings for Pyretron System ($ per ton)

Increase Cost Element	U.S. EPA	Vendor
Initial ACI fee	$−1.35	$−1.40
Increase in capital utilization	28.15	49.12
Labor	132.70	88.44
Propane	99.65	82.60
Oxygen	−221.42	−166.10
Water	−0.90	−0.90
Royalty	−7.50	−7.50
Total	$29.31	$44.24

Source: D13940M, U.S. EPA, 1989.

is provided in Appendix B of the Application Analysis Report (D13940M). According to the U.S. EPA, these data show that for the waste treatment application evaluated, use of the Pyretron system offers significant cost savings over conventional incineration in the case where waste throughput can be increased. However, a number of factors exists that will alter the results of the analysis including:

- Only a complete engineering analysis for a particular incinerator will indicate whether increases in throughput are possible. This is a critical assumption as all subsequent cost calculations are dependent on this fact:
- Incinerator operators who consider retrofitting their equipment to accommodate the Pyretron should consider the cost of equipment modifications:
- Cost savings is heavily influenced by labor requirements and wage rates:
- Interest rates, the capital cost of the incinerator, and the methods for apportioning capital costs will impact the potential for incremental savings:
- Trade-off between oxygen and supplemental fuel source is a direct result of their underlying cost (D13940M, p.17).

T0036

American Soil Technologies, Inc.

Bio-Spin

Abstract
Bio-Spin is an ex situ, bioremediation technology that treats soils contaminated with petroleum hydrocarbons. According to the vendor, the Bio-Spin system first screens and separates oversized debris. Then the system adds enzymes, uses rotation to mix the enzymes and contaminated soil, and then discharges the treated soil into a stockpile. The treated soil is kept separate from surrounding soils until bioremediation is complete.

The vendor stated in 2001 that Bio-Spin is no longer commercially available.

According to the vendor, the technology has several advantages:

- Demonstrates high processing rates.
- Processes soil on site.
- Requires an average of 3 weeks to complete bioremediation.

According to the vendor, the Bio-Spin process is applicable at sites containing more than 100 tons of petroleum-contaminated soil. All information was supplied by the vendor and has not been independently verified.

Technology Cost
According to the vendor, using the ROTAR system and Bio-Spin technology costs approximately \$22 to \$30 per ton of untreated material. The ROTAR system is a small-scale Bio-Spin unit (D22467J).

Information Source

D22467J, Soil Wash Technologies, Inc., 1997

T0037

American Soil Technologies, Inc.

CT-500 Chemical Stabilization System

Abstract
The CT-500 chemical stabilization system is designed to stabilize soils contaminated with hydrocarbons. The vendor states that the CT-500 system binds contaminants in a cementlike, nonsoluble matrix.

The technology is no longer commercially available.

According to the vendor, the CT-500 chemical stabilization system has several advantages:

- Is cost effective.
- Treats contaminated soil on site.
- Produces repeatable treatment results.
- May be modified to combine soil with nutrients or microbes for bioremediation applications
- Is capable of producing a product that can be backfilled on site.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0038

American Soil Technologies, Inc.

SW-400 Soil Washing Unit

Abstract
The SW-400 soil washing unit is an ex situ, treatment technology that removes contaminants from soil using biodegradable chemical surfactants and/or colloidals. The water-based, soil washing process mechanically and chemically scrubs excavated soils. Contaminants are removed from soils by suspension or dissolution within the wash solution. The SW-400 is mobile and transportable and can operate either as a stand-alone technology or in combination with others.

The SW-400 system is currently commercially available.

According to the vendor, the SW-400 Soil Washing system has several advantages:

- Treats contaminated soil on site.
- Is easily transportable.
- Produces a product that can be reused.
- Treats soil containing particles up to 4 inches in size.

In general, soil washing technologies produce a small volume of contaminated soil and/or wash water that requires further treatment. Soil washing is generally not cost effective for soils with more than 30 to 50% silt or clay. The treatment process can be complicated by variable, influent

contaminant concentrations. High humic content in soils supplies additional, contaminant binding sites in the soil and makes treatment more difficult. As with any ex situ technology, the soil to be treated must be excavated prior to treatment. This involves considerable materials handling.

Technology Cost

In general, the treatment costs associated with soil washing technologies vary widely. When the treatment involves physical and chemical soil washing techniques, the Interstate Technology and Regulatory Cooperation (ITRC) Work Group estimates that costs range from $100 to $200 per ton. The percentage of silt and clay in the soil is the primary factor influencing the cost of a soil washing system. Costs are also affected by the organic content of the soil and the soil cation exchange capacity (D19846D, p. 7).

Information Source

D19846D, Interstate Technology and Regulatory Cooperation Work Group, 1997

T0039

Biocube, Inc.

Biocube

Abstract

The Biocube™ aerobic biofilter is an ex situ off-gas filtration system that is commercially available. The technology utilizes microbes to biologically oxidize volatile organic compounds (VOCs) and complex odors. It can be used in conjunction with vapor-vacuum-extraction (VVE), a process that draws gases from subsurface soil. These gases often require further treatment before being released into the atmosphere. Biocube has been field tested and has been implemented at over 100 sites for the treatment of hydrocarbon vapors. The technology has also been successfully used for odor control at a variety of sites. In addition, the Biocube system can treat odor and VOC emissions simultaneously. The units are modular, so additional stacks can be added as needed for increased flow and/or removal rates.

Biocube does have the following potential limitations:

- The gas stream to be treated must be capable of being biodegraded.
- Other hazardous gases may be produced as by-products of the process.
- The system requires an acclimatization period before significant removal efficiencies are achieved
- A drop in media pH may result in odor problems caused by the system's inability to treat organic sulfides and mercaptan compounds.

Technology Cost

The cost for a typical Biocube system averages $28,000. More complex units can cost as much as $300,000. Compared to alternate treatment technologies such as chemical scrubbers, Biocube systems can save the user as much as $115,000 per year (D221454, p. 2).

A Biocube off-gas treatment system installed at a domestic wastewater pumping facility in June 1995 cost $15,000. The pumping facility treats approximately 200 m^3 of water per day (D13550C, pp. 1–4). At a sewage lift station in Miami, Florida, a Biocube unit was installed at a cost of $90,000 (D221465, p. 1).

In Lee County, Florida, three Biocube units and a moisture integrator used for a wastewater application cost $32,740. The Biocube media, which is supposed to be effective for 3 to 5 years, cost \$2100. Power and water expenses for this system were approximately \$1630 per year (D221443, p. 4).

A Biocube system was installed at Patrick Air Force Base in Florida to treat total volatile hydrocarbons (TVH). Because the Biocube failed to meet initial treatment goals during the test, insufficient data was available to evaluate cost. However, the U.S. Environmental Protection Agency (EPA) estimated that costs could range from \$18.66 to \$38.06 per kilogram to treat TVH at concentrations of 1000 to 2000 parts per million volume (ppmv) and flow rates of 20 to 40 standard cubic feet per minute (scfm) (D21034U, p. 1).

At a silver reclamation facility in Duval County, Florida, a Biocube biofiltration system used to treat vapors containing mercaptans (mainly 4-mercapto-4-methyl-2-pentanone) cost \$18,000 (D13551D).

Information Sources

D13551D, EG&G Biofiltration, 1996

D13550C, Singleton et al., 1996

D21034U, U.S. EPA, 2000

D221443, Wong et al., 2000

D221454, Kurvach, 2000

D221465, Odierna, 2001

T0040

Andco Environmental Processes, Inc.

Electrochemical Iron Generation

Abstract

Andco Environmental Processes, Inc., has developed an electrochemical iron generation process to remove hexavalent chromium and other metals from groundwater and aqueous wastes. As contaminated water flows through a treatment cell, electrical current passes between electrodes, releasing ferrous and hydroxyl ions. The small gap between electrodes allows almost instantaneous reduction of chromium ions. Depending on the pH, various solids may form.

The technology is commercially available and has been applied to leachates, wastewater processing, and contaminated groundwater. The technology has been modified to remove hexavalent chromium and immobilize heavy metals in situ, but demonstration results have not been reported.

Electrochemical iron generation is a site-specific technology that is pH dependent. Process pH should be from 6 to 9. Optimal removal efficiencies require electrochemical treatment in combination with an ideal precipitation pH for the metals being removed. Nearly all full-scale systems include a pH control system. Andco performs lab and pilot-scale testing to evaluate the ability of the process to treat a particular waste stream. If flow rates or contaminant loads fluctuate, control equipment is required to compensate for changes in influent.

Technology Cost

Costs associated with electrochemical iron generation are site specific. Factors that can have an affect on process costs include site pH, target contaminants, disposal costs, and any additional treatment required (i.e., air sparging). Cost estimates for two treatability studies are given in Tables 1 and 2. The total cost is \$0.69/1000 gal (\$0.36/2000 liters) for a site in New Jersey, and \$0.32/1000 gal (\$0.17/2000 liters) for a site in South Carolina. The cost estimate prepared for the New Jersey site is based on bench-scale treatability tests. The cost estimate for the South

TABLE 1 Chemical Consumption and Operating Costs—King of Prussia Site

Parameter	Form	Use/Day	Unit Costs	Cost/Day	Cost/1000 gal
Iron	Steel electrodes	72.06 lb	$0.39/lb	$28.10	$0.08
Sodium hydroxide	100% pH adjustment	220.6 lb	$0.28/lb	$61.77	$0.18
Polymer	Anionic emulsion-flocculation	5.75 lb	$1.50/lb	$8.63	$0.02
Cell power	—	1720 kWh	$0.065/kWh	$111.80	$0.32
Pumping and control tower	—	480 kWh	$0.065/kWh	$31.20	$0.09
Total				$241.50	$0.69

Source: Adapted from D112903, 1993.

TABLE 2 Chemical Consumption and Operating Costs—South Carolina Site

Parameter	Form	Consumption	Unit Costs	Cost/$1000 gal
Iron	Steel electrodes	6.1 lb	$0.39/lb	$0.08
Hydrochloric acid	35%	6.2 lb	$0.095/lb	$0.04
Sodium hydroxide	50%	6.3 lb	$0.28/lb	$0.18
Polymer	Anionic emulsion	6.4 lb	$2.90/lb	$0.03
Cell power	—	28 kWh	$0.06/kWh	$0.06
Pumping and control power	—	34 kWh	$0.06/kWh	$0.07
Total				$0.32

Source: Adapted from D125188, 1994.

Carolina site is based on the treatment of 28,336 gal (107,000 liters) of water during a pilot-scale treatability study. The main difference between the two estimates is the higher electricity costs associated with Case Study 1.

Information Sources

D112903, Brewster, 1993

D125188, Brewster and Passmore, 1994

T0041

AP Technologies, Inc.

Mercrobes Mercury Reduction Technology

Abstract

Mercrobes mercury reduction technology (Mercrobes) is a proprietary, ex situ technology for the treatment of soils, sludges, sediments, and waters contaminated with mercury and mercury compounds. The process uses proprietary microbes to reduce organic and inorganic mercury compounds to elemental mercury. The vendor claims that in addition to reducing charged

mercury, Mercrobes can “disintegrate” some organic compounds such as “benzenes, toluenes, etc.” to carbon dioxide and water.

According to the vendor, following the mercury reduction step, the elemental mercury can be recovered using standard technologies, e.g., vapor extraction.

All information is from the vendor and has not been independently verified. The technology does not appear to be commercially available; RIMS was unable to contact the vendor.

Technology Cost
No available information.

T0042

Applied Environmental Services, Inc.

Asphaltic Metals Stabilization

Abstract
Asphaltic metals stabilization is a stabilization technology for metal-contaminated soils in which the soils are combined with predetermined amounts of aggregates and asphalt emulsions to

TABLE 1 Asphaltic Metals Stabilization (AMS) vs. Hazardous Waste Landfill Disposal (HWLD) Cost Comparison

Task	Description	AMS	HWLD	Difference (per ton)
1.0	Sample and analyze affected material in place in clarifiers	$3200.00 lump sum	$3200.00 lump sum	0
2.0	Excavate and load affected material	$2200.00 lump sum	$2200.00 lump sum	0
3.0	Transport material	$3.25/ton	$37.50/ton	$34.25
4.0	AMS process vs. disposal of material	$40.00/ton	$150/ton	$110.00
5.0	Value of finished product as assigned by client	$20.00/ton	0	$20.00
6.0	State taxes for disposal of hazardous waste			
	Superfund HW landfill	0	$52.50/ton	$52.50
	Hazardous waste disposal fee	0	$105.00/ton	$105.00
	Generators fee and surcharge	0	$6.00/ton	$6.00
	County tax	0	$9.50/ton	$9.50
	Totals per ton	$23.25/ton	$360.50/ton	NA
	Difference per ton AMS vs. HWLD	0	0	$337.25
	Additional analytical performed on the AMS finished product for the purpose of this test	$1100.00 ($50.00/ton)	0	−$50.00
			Net	$287.25

create a commercially viable asphalt product. RIMS was unable to contact the vendor, therefore, the commercial availability of the technology is unknown. A similar technology has been demonstrated for soils contaminated with petroleum hydrocarbon.

All information was submitted by the vendor and could not be independently verified.

Technology Cost

Table 1 gives a cost comparison of asphaltic metals stabilization (AMS) versus hazardous waste landfill disposal (HWLD). The AMS eliminated $173.00/ton in state and county taxes.

Information Source

D15632L, Testa, Patton, 1992

T0043

Applied Membrane Technology, Inc. (AMT)

In Situ Oxygen Diffuser

Abstract

The Applied Membrane Technology, Inc.'s (AMT) in situ oxygen diffuser system is an in-well device that creates a continuous, circular flow of oxygen-enriched water in an aquifer. The system uses AMT's AEROX™ membrane cartridges, which use gas-filled, hollow fiber membranes designed to dissolve oxygen directly into water without forming bubbles. The developer claims that the cartridges permit approximately 100% oxygen transfer efficiency to contaminated groundwater without venting toxic volatile organic compounds (VOCs) (i.e., benzene, toluene, and xylenes) into the air.

AMT holds U.S. patents on several membranes, including the basic patents on the coated microporous fibers used in the oxygenated system.

According to the developer, the technology has the following advantages:

- Design allows tolerance of small particulates and suspended solids usually found in properly screened walls
- System's polymer film properties and free oscillation as a fluidized array resists biofouling and iron clogging

Additionally, the developer notes that providing sufficient oxygen is usually the primary limiting factor in aerobic biodegradation processes.

Technology Cost

No available information.

T0044

Applied Natural Sciences, Inc.

TreeMediation

Abstract

TreeMediation is a phytoremediation technology offered by the vendor as an alternative to pump-and-treat technologies and is based on certain tree species' abilities to extract large quantities of water from aquifers. TreeMediation uses plant species to assimilate contaminants or to

TABLE 1 Cost Comparison Between TreeMediation and Pump-and-Treat System

Pump-and-Treat System		TreeMediation	
Equipment[a]	$100,000	Design and implementation	$50,000
Consulting	25,000	Monitoring equipment	
Installation/construction	100,000	Hardware	10,000
		Installation	10,000
		Replacement	5,000
5-year costs		5-year monitoring	
Maintenance	105,000	Travel and meetings	50,000
Operation	50,000	Data collection	50,000
Waste disposal	180,000	Annual reports	25,000
Waste disposal liability	100,000	Effectiveness assessment—sample collection and analysis	50,000
Total	$660,000	Total	$250,000

[a] Off-the-shelf equipment, three pumping wells, and a reverse osmosis treatment system.

create environments conducive to the degradation of contaminants through natural biochemical processes. The use of plants for remediation is often called phytoremediation.

TreeMediation is a commercially available, although still evolving, technology. It was started in 1990 and has been applied at seven total sites.

According to the vendor, one potential advantage of the technology is that the trees flush water upward through the soil column. This process can be much more effective at remediation than traditional pump-and-treat systems by limiting additional leaching of contaminants into the aquifer. The vendor also lists the following as advantages of TreeMediation:

- In situ
- Environmental compatibility
- Efficient low-tech alternative
- Low maintenance
- Low capital costs

This technology is limited to treating aquifers shallower than 30 ft. Using trees for phytoremediation offers no guarantees that the root system will extend below the top 3 or 4 ft of soil. In areas where rainfall is moderate to heavy, or where the climate is humid, trees are provided with more than enough water in the first few feet of soil to not only survive, but also thrive. Plants will naturally conserve their resources and will typically expend only the energy necessary to maintain viability.

Plants are living organisms with constraints that are often in conflict with the nature of the pollutant and/or the possibly industrial setting to be remediated. These include pH, texture, ionic, nutrient, and growth constraints. However, many soils initially hostile to plants can be converted to reasonable growth media with proper amendments. In addition, phytoremediation is a slower process than alternative technologies, and cleanup often requires several growing seasons.

Technology Cost

At a site in Illinois, TreeMediation was coupled with a pump-and-treat system to mitigate an immediate "at-risk" situation of off-site movement of a contaminated plume containing nitrogen and pesticides. This problem provided an opportunity to compare the costs of the two systems. Costs are estimated in round numbers for a 1-acre site with an aquifer 20 ft deep. Costs common to both approaches, such as meetings with regulators and laboratory analyses, were not included. Results are given in Table 1 (D12674J, p. 350).

General cost estimates for phytoremediation range from $3 to $100 per cubic meter. The annual costs of using phytoremediation in a cropping system is approximately $0.02 to $1 per cubic meter. These annual costs are significantly less than the costs associated with alternative remediation technologies (D20756H, p. 42).

Because phytoremediation utilizes solar energy, the technology requires few energy inputs. This factor reduces operating costs. Expenses are also spread out over a greater time period than other technologies since phytoremediation is a slower treatment process. The result is lower annual costs. Frick et al. also note that "agronomic costs, including planting, tillage, fertilization, and harvesting, can be insignificant in comparison with associated administrative costs, such as site management, regulatory reporting, and analysis of data" (D20756H, pp. 42, 43).

Information Sources

D12674J, Gatliff, Remediation, 1994
D20756H, Frick et al., 1999

T0045

Applied Research Associates, Inc.

Biodegradation of Perchlorate

Abstract

Applied Research Associates, Inc. (ARA), has developed and helped commercialize a biological treatment system for degrading ammonium perchlorate. The system utilizes a bioreactor containing a specialized microorganism that converts perchlorate to chloride. The technology was originally designed, tested, and built by ARA for the U.S. Air Force Environics Laboratory. It has been used to treat industrial wastewater and has been evaluated for use in treating perchlorate-contaminated groundwater and drinking water. The process is patented and commercially available.

According to the vendor, the ARA process has the following advantages:

- The process can reduce perchlorate concentrations below detection limits.
- It is effective at treating perchlorate in the presence of other contaminants, such as nitrate, chlorate, sulfate, ammonium, dissolved solids, dissolved metals, and volatile organic compounds (VOCs).
- It is effective over a wide range of initial perchlorate concentrations.

Using the technology to treat wastewater at low temperatures (less than 15°C) may require longer residence times as well as nutrient adjustments.

Technology Cost

According to the vendor, operation and maintenance costs for a full-scale groundwater treatment system would be less than $1 per kilogram of perchlorate removed. This estimate includes costs associated with nutrient and chemical additions, as well as power and labor costs. ARA's groundwater treatment systems are designed to operate at 50 to 450 gal/min and to remove 1000 to 2000 lb of perchlorate per day. The vendor states that a system designed for the treatment of perchlorate-contaminated drinking water would cost $100 to $200 per acre-foot (D222060, pp. 3, 4).

During pilot-scale tests conducted by the U.S. Air Force, the nutrients used with this technology were brewer's yeast and a water-soluble brewer's yeast extract (BYF-100). Brewer's yeast costs $0.40 per pound. BYF-100 costs $2.00 per pound (D18070L, p. 2).

In 1997, the technology was incorporated into Thiokol Corporation's waste treatment facility near Brigham City, Utah (D22204Y, p. A58). This system initially used brewer's yeast and a cheese–whey mixture as nutrient sources. In an effort to reduce costs, these additives were replaced with a carbohydrate by-product. As a result, chemical and nutrient costs dropped by more than 90%, from approximately \$1.76 to \$0.16 per pound of perchlorate removed (D22204Y, p. A59).

Information Sources

D18070L, U.S. Air Force, undated

D22204Y, Ground-Water Remediation Technologies Analysis Center, 2001

D222060, Applied Research Associates, Inc., undated

T0046

Aprotek

Ion Conduction Agglomeration System

Abstract

The high tension ion conduction agglomeration (INCA) system is an ex situ process for the recovery of soluble and particulate metals from aqueous solutions such as mining effluents, process waters, and wastewater. It is not known if the technology is currently commercially available.

The INCA system can recover virtually any target metal in any aqueous waste stream containing up to 60% solids. Applications include on-site remediation of mining effluents and contaminated groundwater. The INCA system can also be used as an in-process treatment system for manufacturing processes where metals in solution are a problem. The modular unit can easily be used in tandem with other technologies, such as those that remove hydrocarbons, as part of a total treatment train.

Technology Cost

According to vendor-supplied information, the INCA system can process aqueous solutions efficiently and greatly reduces costs for two major reasons: (1) the technology costs much less than traditional treatment methods, and (2) the value of precious metals recovered during the process could offset the cost of remediation and may even result in a profit (D10759F, pp. 180–181). No specific cost information was available.

Information Source

D10759F, U.S. EPA, October 1995

T0047

Aqualogy BioRemedics

Environmental Quality NutriBac

Abstract

NutriBac is a product in a line of environmental quality biocatalysts offered by Aqualogy BioRemedics. NutriBac is designed to increase the metabolic activity of digester bacteria and provide a wastewater treatment system that optimizes bioremediation through bioaugmentation. According to the vendor, NutriBac provides optimal micronutrient composition for bioremediation processes especially where nutrients are lacking. NutriBac superactivates microbial blends in all environmental quality products. NutriBac contains no bacterial inoculants or enzyme material. It superactivates the existing beneficial microorganisms and does not add new ones. NutriBac is nontoxic, noncorrosive, and has no chemical additives.

According to the vendor, this technology is no longer commercially available.

All information is from the vendor and has not been independently verified.

Technology Cost

The cost of Environmental Quality NutriBac is $688 per ton (D16406H, p. 1).

Information Source

D16406H, http://www.aqualogy.com

T0048

Aqualogy BioRemedics

Environmental Quality PetroKlenz

Abstract

PetroKlenz is a product in a line of environmental quality biocatalysts offered by Aqualogy BioRemedics. PetroKlenz is designed for the biotreatment of fresh or weathered crude oil, heavy tarry petroleum derivatives, oil sludge, and aromatic and aliphatic hydrocarbons. PetroKlenz is a dry powder containing specific cultured facultative anaerobes, naturally occurring microbes that were originally derived from soil and have been preserved through advanced drying techniques. The various strains are grown individually in pure culture and compounded together with powdered wetting agents, buffering agents, and other synergists that allow the organisms to readily adapt to the treatment environment. The organisms have been carefully matched to complement each other for the effective biodegradation of organic hydrocarbons.

This technology is currently commercially available.

Dry environmental quality PetroKlenz must be reconstituted with water and made into a slurry. The organisms will be ineffective if they are applied as dry cultures over the oil. The effective use of PetroKlenz in a biotreatment program is dependent upon the environmental conditions present at the site. Adverse conditions such as cold temperatures, oxygen, nitrogen, or phosphorus-deficient water, chemical toxic load, highly acidic or alkaline conditions, or excessive dilution of biomass by tides and currents, may retard or prevent biodegradation.

Technology Cost

According to the vendor, the cost for PetroKlenz is $17,775 per ton of material used (personal communication, T. Rothweiler, Aqualogy BioRemedics, 11/97 and D16406H). The vendor states that smaller quantities are commercially available at the following prices:

2 lb, $59.90
10 lb, $269.50
25 lb, $636.25
50 lb, $1122.75
100 lb, $2095.80

Information Source

D16406H, http://www.aqualogy.com

T0049

Aqualogy BioRemedics

OptiSorb Encapsulate

Abstract
OptiSorb Encapsulate is a homopolymer powder that is designed to absorb petroleum and other hydrocarbon-based materials. According to the vendor, OptiSorb Encapsulate can be used on hydrocarbons such as kerosene, gasoline, diesel fuel, crude oil, transformer oil, jet fuel, and other chemicals such as benzene and xylene. Aqualogy BioRemedics states that OptiSorb Encapsulate can be used to clean up hydrocarbon spills on waterways and on land. Other uses of OptiSorb Encapsulate include use in industrial factories, storage facilities, and refineries.

This technology is currently commercially available.

All information is from the vendor and has not been independently verified.

Technology Cost
According to the vendor, the cost of the OptiSorb Encapsulate powder is $20,400 per ton (D16406H, p. 1). The vendor states that smaller quantities are commercially available at the following prices:

25 lb, $375.00

50 lb, $750.00

100 lb, $1275.00

(Personal communication, T. Rothweiler, Aqualogy BioRemedics, 11/97)

Information Source

D16406H, http://www.aqualogy.com

T0050

Aquathermolysis

Abstract
Aquathermolysis is a technique that holds promise for use in the remediation of inorganic and organic contaminants in soils or aquifers. In the aquathermolysis process, water acts as the catalyst, reactant, and solvent and requires the addition of no other acids, bases, or catalysts. Typically, the technique works by heating water to 200 to 450°C in a container under pressure. At these temperatures water can mimic a basic or acidic chemical solvent and can actually help break down contaminants. The higher the temperature, the greater the ability of the water to act as an organic solvent. Once heated, the water can be used as part of an in situ or ex situ treatment process. For example, heated water can be injected into a contaminated area or used in soil washing processes.

Laboratory studies indicate that aquathermolysis can be used to aid in the remediation of waste oils, chromium (Cr VI) and volatile organic compounds (VOCs) in contaminated soils and aquifers. Aquathermolysis is particularly useful in lowering the viscosity of oil and increasing its mobility to facilitate further treatment. Potential applications range from treating household and industrial refuse to destruction of chemical warfare agents.

An advantage of aquathermolysis is that the use of hot water as a remediation technique does not require the injection of potentially harmful chemicals. Additional advantages include the lower temperatures and pressures that are easier to produce and handle in the injection

equipment and wells. In contrast to the high temperatures used for steam injection, which are detrimental to the microorganisms commonly found in the subsurface, moderate temperatures may be beneficial to subsequent bioremediation.

Some research has shown that emulsions are formed when hot water or steam is used to displace oil from porous media. The formation of emulsions would adversely affect efforts to recycle the water and would likely increase the amount of treatment that the water would require before it could be discharged.

Technology Cost
No information available.

T0051

ARC Sonics, Inc.

Sonic Reactor (or Sonic Grinder)

Abstract
The ARC Sonics, Inc. (ARC), sonic reactor (or sonic grinder) is an ex situ technology that uses enhanced oxidation and sonic mixing to treat contaminated soils. The sonic reactor disperses agglomerated soils (e.g., clay), forming dilute slurries of finely suspended particles. The particles are passed through a reaction chamber where hazardous organic contaminants that are trapped in the soil are treated with oxidizing agents, hydrogen peroxide, and ozone. An ultraviolet (UV) light source is used to enhance contaminant oxidation.

The technology primarily treats clays because their physical and chemical properties, such as external and internal active surfaces produced by their fine crystalline structure, make them difficult to decontaminate. ARC asserts that pilot studies showed that the technology works well on perchloroethylene (PCE), xylene, phenols, and polychlorinated biphenyls (PCBs).

The ARC sonic grinder is applicable in the following areas:

- Fine chemicals such as anthraquinone (used in paper production)
- Pharmaceuticals—micronized for fast absorption
- Cosmetics
- Powdered metallurgy/advanced ceramics; fine powder sinters and bonds very quickly
- Fillers and specially coated color printer paper
- Pigments and coatings—fine pigments (easier to suspend) for water-based paints

Technology Cost
The company is interested in forming partnerships with industrial companies to conduct demonstration projects (Personal communication, John P. Russell, Vice President of ARC Sonics, 1996). No information is available regarding the costs associated with this technology.

T0052

ARCADIS Geraghty and Miller, Inc.

In situ Reactive Zones Using Molasses

Abstract
In situ reactive zones using molasses is an in situ bioremediation technology that precipitates heavy metals and destroys organic contaminants in groundwater. The technology uses

molasses injection to create anaerobic conditions in the subsurface and enhance microbial activity.

The vendor states that technology has been tested in pilot- and full-scale field demonstrations at over 85 sites in the United States and Europe. In situ reactive zones using molasses is commercially available.

According to the vendor, the technology has the following advantages:

- Generates a relatively small amount of remediation waste when compared to ex situ technologies.
- Uses a highly soluble, off-the-shelf, low-cost electron donor.
- Destroys halogenated organic compounds and precipitates heavy metals.
- Is applicable to various geological settings and aquifer conditions.
- Uses indigenous microorganisms, avoiding the introduction of foreign organisms.
- Reduces the risk of human exposure to contaminated media.

The toxicity of the degradation products may exceed the toxicity of the parent compounds. Heavy metals are converted to less soluble forms; they are not removed from the subsurface. Heterogeneities in the subsurface may cause the uneven distribution of nutrients during direct-injection applications. Injection may be slower in formations with low hydraulic conductivities. Smaller reactive zones may also form in areas with low hydraulic conductivities.

Technology Cost

At an abandoned manufacturing facility in Emeryville, California, the groundwater was contaminated with hexavalent chromium and up to 12,000 micrograms per liter (μg/liter) of trichloroethene (TCE). A pilot-scale demonstration of in situ reactive zones using molasses was conducted in 1995 and 1996. In 1997, the project was expanded to a full-scale application. The full-scale system used 91 temporary injection points to deliver molasses to the subsurface. The overall project cost was approximately $400,000 (D210571, p. 90).

The groundwater at the 2-acre Avco Lycoming Superfund site in Williamsport, Pennsylvania, was contaminated with chlorinated solvents, cadmium, and hexavalent chromium. Following a successful pilot-scale demonstration that lasted from 1995 through 1996, the technology was applied on a full-scale. The cost of the pilot-scale demonstration was approximately $145,000. The full-scale remediation system cost about $220,000 to construct. Operation and maintenance costs have been approximately $50,000 per year (D210571, p. 93; D213376, p. A-47).

Information Sources

D210571, Federal Remediation Technologies Roundtable, 2000

D213376, U.S. EPA, 2000

T0053

ARCADIS Geraghty and Miller, Inc.

STRATEX

Abstract

STRATEX, or the stratified temperature extractor technology, is an integrated ex situ soil treatment technology that uses solidification/stabilization, thermal desorption, and steam stripping.

The STRATEX technology converts soils, sludge, and debris that are contaminated with both organic and inorganic contaminants into a stabilized form. The STRATEX technology removes toxic organic compounds and volatile metals in a low-volume, concentrated stream and simultaneously stabilizes nonvolatile organics, metals, and/or low-level radioactive waste constituents. Thermal desorption and steam stripping remove the organic contaminants and volatile metals. Solidification/stabilization helps to immobilize inorganic and radioactive contaminants, facilitating safe disposal of treated soil.

The technology treats polychlorinated biphenyls (PCBs), dioxins, volatile metals (such as mercury), and nonvolatile metals (such as lead or transuranic radioactive elements).

The advantages of the STRATEX technology noted by the vendor include:

- A simple mechanical design with few moving parts and no tight areas where debris might lodge, making the STRATEX technology less sensitive to variability in feed streams
- Technical and cost advantages over existing technologies, since organic and inorganic species are treated in the same process stream
- Debris in soil handled by passing the debris through the system and embedding it in a stabilized finished product
- Smaller air pollution equipment than that presently used in thermal treatment systems requiring a noncondensable purge gas
- Elimination of the need for large heat transfer surfaces
- Reduction of the formation of large quantities of contaminated particulates by extracting water chemically rather than by boiling
- Use of a condensable gas that reduces the resultant gas stream to be treated, making it less costly than conventional thermal desorption systems

In comparison to incineration, the STRATEX technology does not remove nonvolatile organics such as plastics from treated material. Among the factors listed as items of concern for the scaled-up model of the STRATEX system are the depth of the soil (or other solids) found in the STRATEX device during or after treatment and maintenance of the solids residence time at the proper temperature.

This technology is no longer commercially available from this vendor.

Technology Cost

Based on the treatment of 50,000 tons of contaminated material, the preliminary cost estimate for using the STRATEX technology is approximately \$125 to \$150 per ton of material processed. The preliminary cost estimations include preliminary estimates of the operations and maintenance costs, including labor costs, system transport costs, binder costs, fuel costs, and travel costs (D14167D, p. 6).

The following costs are preliminary bench-scale startup costs for the STRATEX technology [D14167D, p. 6; Personal communication: Michael Mann, ARCADIS Geraghty and Miller, Inc. (formerly Alternative Remedial Technologies, Inc.), December 1996]:

- Estimated cost, \$1,000
- Development costs, \$500
- Procurement and construction, \$500
- Permitting, \$100
- Other costs, \$50

Information Source

D14167D, STRATEX for Treatment of Soils, September 18, 1994

T0054

Arctech, Inc.

Humasorb

Abstract
Humasorb™ is an adsorbent used for single-step removal of organic contaminants, heavy metals, and radionuclides from contaminated waste streams. The technology is based on the capacity of humic acid to capture and remove contaminants. According to the vendor, the material has a high cation exchange capacity, the ability to chelate metals, and the ability to absorb organics. Humasorb is a proprietary product and was developed from another Arctech product called actosol®, a humic-acid-based soil conditioner. Humasorb has been field tested and is commercially available through Arctech.

The adsorbent can be used in several ways for field applications. In one method, the material can be placed into a trench installed in the path of a contaminant plume. The material will form an in situ permeable barrier, removing contaminants as they pass through the Humasorb. Another method involves injecting or augering the adsorbent into the soil to accomplish the same task. The technology can also be applied as part of an ex situ remediation system.

Technology Cost
The vendor states that one version of the technology, known as Humasorb-CS™, costs $2000 per ton of product. According to the vendor, Humasorb-CS is three to five times less expensive than alternative barrier technologies (D22186D, p. 19). For some applications, costs may be offset by profits generated from the sale of micronutrient fertilizer recovered during the treatment process (D20865L, p. 45; D22185C, p. 2).

In 1998, it was estimated by researchers at Argonne National Laboratory East that the use of Humasorb as a polishing step after hot air injection and in situ mixing would be approximately $58/yd^3 of soil treated. The mixing and air injection costs on clay soil were estimated to be $30/yd^3, bringing the total cost of treatment to $88/yd^3. Costs were based on treating 20,000 yd^3 of contaminated soil. For this estimate, the vendor also provided researchers with information on expected reagent use and cost (D185722, p. 24).

At the Berkeley Pit Superfund site in Butte, Montana, Humasorb was tested for removing heavy metals from groundwater. Based on pilot-scale studies, it was determined that total cleanup costs at the site using Humasorb would be $51 million. These costs included the expenses associated with pumping groundwater from the pit for treatment (D19033K, pp. 1, 2).

Information Sources

D18882D, Federal Remediation Technologies Roundtable, 1998

D185722, Day and Moos, 1998

D19033K, U.S. EPA, 1999

D20865L, Sanjay et al., 1999

D22185C, Arctech, Inc., undated

D22186D, Sanjay, 1998

T0055

Arctech, Inc.

Bioremediation

Abstract
The Arctech solid-phase bioremediation composting technology is an accelerated biological process used to degrade organic compounds in water, soil, and/or sediment. The Arctech technology

can treat organic pesticides, herbicides, polychlorinated biphenyls (PCBs), polynuclear aromatic compounds (PNAs), explosives, and propellants.

The technology can be used in agricultural applications, the manufacture or use of herbicides, munitions manufacturing, and in the manufacture and use of pesticides.

The technology uses composting and, according to the vendor, offers both economic and portability advantages when compared to other available technologies that are currently being used to treat or dispose of soil, sediment, or water contaminated with energetic materials (explosives and propellants).

The technology has been applied to pilot-scale treatability studies, but is presently not commercially available (December 1996).

Technology Cost

The Arctech technology costs approximately $32.00 to $150.00 per cubic yard of material processed (D10018L, p. 13).

Among the factors that affect the cost per unit price are initial contaminant concentration, target contaminant concentration, moisture content of the soil, and soil characteristics (D10018L, p. 13).

Information Source

D10018L, VISITT 4.0

T0056

Arctech, Inc.

Light-Activated Reduction of Chemicals (LARC)

Abstract

Light-activated reduction of chemicals (LARC) is a patented, ex situ method for the dehalogenation of organic compounds using ultraviolet (UV) light and an optimized reducing environment. The LARC process includes the liquid extraction of chlorinated, brominated, and iodinated organic compounds and the subsequent dehalogenation of these compounds via photochemical reduction. LARC can be used for the treatment of soils, sludges, sediments, liquids, and solid wastes. The halogenated organic compounds can be treated in the presence of other organic or inorganic material as long as sufficient UV light can be transmitted and free radical reactions can be maintained.

The LARC process has proven successful in the laboratory for the treatment of toxic wastes containing polychlorinated biphenyls (PCBs), pesticides such as chlordane and kepone, and other halogenated compounds. According to the vendor, the photochemical conditions supplied by the LARC reactor lead to a rapid, highly controllable reaction that yields only biphenyl and sodium chloride as the final products from PCBs. No oxygenated derivatives, chlorinated dibenzofurans, or chlorinated dioxins have ever been observed in gas chromatographs or mass spectra of the intermediates or products in the LARC degradation of chlorinated organics.

LARC technology was designed specifically for the treatment of halogen containing materials. It cannot treat metals or radioactive waste.

Technology Cost

The cost of treating soil contaminated with PCBs using LARC, including daily operation, labor, laboratory analyses, travel, per diem expenses, and profit was estimated to be $85 per ton of soil in 1984. This cost was estimated based on laboratory studies using soil with an average level of PCB contamination of 1500 parts per million (ppm). Alternatively, the cost of landfilling PCBs was estimated to be from $170 to 220 per ton of soil (D14265E, p. 115).

Information Source

D14265E, Kitchens et al.,1984

T0057

Arctech, Inc.

Ozo-Detox

Abstract
The Ozo-Detox™ ex situ oxidation technology destroys volatile and nonvolatile organic contaminants in soil and water on site by reaction with dissolved ozone, hydrogen peroxide, and catalysts in aqueous solution. The technology leads to rapid oxidation of contaminants with over 90% destruction with minimal contact time. Contaminants treated include petrochemicals, polyaromatic hydrocarbons (PAHs), and materials contaminated, with heavy hydrocarbons. The technology is specifically designed to treat coal gasification sites, oil/tar-contaminated sites, and wood-preserving sites. It is currently available as a pilot-scale system.

The vendor claims that it is notably faster than bioremediation and provides a more permanent solution than stabilization technologies. It is also claimed that this technology is significantly less expensive than incineration and thermal destruction.

The technology is not applicable to wastes containing only metals, radioactive compounds, and inorganic corrosive materials. The performance can be limited by the presence of radical scavengers, such as acids.

Technology Cost
No available information.

T0058

Arctic Foundations, Inc.

Cryogenic Barrier

Abstract
The Arctic Foundations, Inc. (AFI), frozen soil barrier technology is constructed by artificially freezing the soil pore water. As the pore water freezes, the soil permeability decreases, thereby forming an impermeable barrier that surrounds and contains the contaminants. When properly installed, the frozen soil barrier prevents the migration of contaminants within groundwater and soil. Contaminants are contained in situ, with the frozen native soils serving as the containment medium. The contaminants are isolated by the wall until appropriate remediation techniques can be applied.

In the past, this technology has been used for groundwater control and to strengthen walls at excavation sites. According to the vendor, the principle aspects of this technology have been demonstrated in various applications for nearly 50 years. The technology is currently commercially available.

This technology does not change any hazardous characteristics of the waste, it is used only for containment.

Advantages of frozen barriers include the following features:

- Is environmentally safe.
- Lower risk and cost (relative to other containment technologies) because the soil is not excavated and there are no by-products.

- Wall can be installed in almost any size and configuration.
- Can provide complete containment (“V” configuration).
- Ice does not degrade or weaken over time.
- Laboratory tests have achieved hydraulic conductivities of less than 4×10^{-10} cm/sec in soils.
- Once installed, easy to maintain and repair in situ.
- Is removed by thawing.

Limitations of frozen barriers include:

- No long-term data
- Amount of energy and time required to form the barrier dependent on the soil matrix
- Drilling required to install freeze probes a constraint in certain soil types

Technology Cost

Table 1 gives cost and maintenance information for the frozen barrier installed as part of the U.S. Environmental Protection Agency Superfund Innovative Technology Evaluation (SITE) demonstration at Oak Ridge National Laboratory (ORNL). Table 2 gives physical design data for the ORNL project.

Information Sources

D17702Q, Arctic Foundations, Inc., undated web site

D17454T, Arctic Foundations, Inc., 1998

D18978K, Pearlman, 1999

D19013G, U.S. EPA, 1999

TABLE 1 Cost and Maintenance Summary for Cryogenic Barrier Technology

Project cost (approximation)	$1,809,000[a]
Project installation	$1,252,778
Power to freeze barrier (67,000 kWh)	$3,500
Site power ($ per kWh)	$0.052
Freezeback (cost per ft^2) [freezeback to 12 ft (61,416 kWh or 1.758 ft^2/kWh)]	$139.20
Freezeback (cost per ft^3) [freezeback to 12 ft (61,416 kWh or 1.758 ft^3/kWh)]	$11.60
Power only (cost per month)	$477
Total maintenance cost per day	$54.59
Maintenance cost per ft^2/day	$0.0061
Maintenance cost per ft^3/day	$0.0005
Total maintenance cost per year	$19,925.00
Total maintenance cost per ft^2/year	$2.21
Total maintenance cost per ft^3/year	$0.18

Source: Adapted from D17702Q, D18978K, and D19013G.

[a] Cost approximation includes design, installation, startup, system operation, engineering oversight, site infrastructure upgrades, and pre- and postbarrier verification studies.

TABLE 2 Physical Design Data for the ORNL Project

Frozen barrier volume	108,000 ft^3
Contained volume	1,658,750 ft^3
Frozen barrier surface	9,000 ft^2
Initial soil temperature	Approximately 66°F
Length	300 ft
Depth	30 ft
Wall thickness	12 ft
Number of freeze probes	50
Freeze probe spacing	6 ft
Active refrigerant	R-404A
Passive refrigerant	Carbon dioxide
Evaporator temperature	−25°F (capable of −40°F)

Source: Adapted from D17702Q and D18978K.

T0059

Argonne National Laboratory

Advanced Integrated Solvent Extraction and Ion Exchange Systems

Abstract
The advanced integrated solvent extraction (SX) and ion exchange (IX) systems are a series of novel SX and IX processes intended to extract and recover uranium, transuranics (TRUs) (e.g., neptunium, plutonium, americium), and fission products (^{90}Sr, ^{99}Tc, and ^{137}Cs) from acidic high-level liquid (or sludge) waste. The systems are intended to sorb and recover ^{90}Sr, ^{99}Tc, and ^{137}Cs from alkaline supernatant high-level liquid waste. Each system uses new selective liquid extractants or chromatographic materials. The integrated SX and IX processes are intended to reduce the quantity of waste that must be vitrified and buried in deep geologic repositories by producing raffinates (from SX processes) and effluent streams (from IX processes) that meet the specifications of class A low-level waste. The processes should also reduce vitrification requirements by reducing levels of alpha activity.

The advanced integrated solvent extraction and ion exchange systems are designed for the chemical pretreatment of waste retrieved from storage tanks at Department of Energy (DOE) sites (e.g., at INEL, Hanford, Savannah River).

Technology Cost
No available information.

T0060

Argonne National Laboratory

Aqueous Biphasic Extraction System

Abstract
An aqueous biphasic system consisting of two immiscible liquid phases (i.e., two separate distinct layers) can be used to separate a particular component such as certain heavy metals from contaminated soil. A combination of phases such as a water-soluble polymer (e.g., polyethylene glycol) phase and a concentrated aqueous salt solution (e.g., sodium carbonate, sodium sulfate, or sodium phosphate) phase can comprise a biphasic system. Aqueous biphasic systems are

similar to conventional solvent extraction systems used for waste treatment applications, except that there is no organic phase.

Aqueous biphasic systems offer the potential for highly selective and low-cost separations. Aqueous biphasic extraction for soil decontamination is based on the selective partitioning of either dissolved solutes or ultrafine particulates between two immiscible aqueous phases. Both soluble and particulate uranium contaminants can be separated from soil using this technique. Aqueous biphasic extraction may also have application for separation of plutonium and thorium from soil or waste.

Laboratory-scale studies indicate that the aqueous biphasic process is well suited to the recovery of ultrafine, refractory material from soils containing significant amounts of silt and clay. The main advantages of the aqueous biphasic system in treatment of uranium-contaminated soils are that the process achieves a high removal rate for the uranium contaminant and that such removal is highly selective. Laboratory studies indicate that approximately 99% of the soil is recovered in the clean fraction.

The aqueous biphasic extraction technology also has potential for the treatment of process wastes that contain high concentrations of salts such as sodium carbonate, sulfate, or phosphate.

Aqueous biphasic systems have been used commercially for protein separations, separation of metal ions, ultrafine particles, and organics. Application of the technology for soil decontamination has only been demonstrated in laboratory-scale studies.

Technology Cost

Preliminary estimates for full-scale treatment costs of uranium-contaminated soils were developed based on laboratory-scale studies. The process design uses polyethylene glycol (PEG) (15% solution) and sodium carbonate (10% salt solution) for the aqueous biphasic extraction system. Uranium is recovered from the salt-rich phase by methanol precipitation. Methanol is then recovered by distillation.

Assuming a 480-ton/day treatment rate, the estimated life-cycle cost for a full-scale treatment is approximately \$160 per ton of dry soil processed (D13753L, p. 2). This estimate includes fixed capital investment and operating costs based on a 70% utilization factor for plant operations over a period of 17 years. Operating cost estimates (included in the life-cycle cost estimate) include an inflation rate of 5% per year (D13753L, pp. 32–34).

The cost estimate of \$160 per ton of dry soil takes into account losses of carbonate, PEG, and methanol. The in-process loss of PEG (about 6 lb PEG per ton of soil) is due primarily to irreversible adsorption of PEG onto the soil surface (D13753L, p. 29). About 44 lb of carbonate per ton of soil are lost. Methanol losses occur primarily through incomplete recovery from the distillation step.

The most expensive operation of the process is the secondary treatment of the salt-rich phase involving methanol precipitation/distillation (D13753L, p. 2). Further research on alternative methods for the removal of dissolved uranium from concentrated sodium carbonate are underway.

It is expected that processing costs can be reduced by further development and by scale-up to higher treatment rates.

Information Source

D13753L, Chaiko et al., Argonne National laboratory Report, 1995

T0061

Argonne National Laboratory

Biocatalytic Destruction of Nitrate

Abstract

Biocatalytic destruction is the focus of an ongoing project to develop an enzyme-based reactor system that uses naturally occurring reductase enzymes to reduce nitrate and nitrite present

in various aqueous wastes to nitrogen and hydroxide ions. This technology is not currently available. Currently, only nitrate reduction to nitrite has been demonstrated. Work on nitrite to nitrogen gas conversion was to be performed in later stages of this project. This technology never received funding and studies were eventually discontinued.

According to the vendor, this project could provide a compact, low-cost reactor to treat aqueous mixed waste streams containing nitrates or nitrites, eliminate the need for chemical reagents, and minimize or eliminate secondary wastes such as nitrous oxide and secondary products such as ammonia, H_2, and O_2 that are prevalent with other nitrate destruction processes. By removing nitrates and nitrites from waste streams before they are sent to high-temperature thermal destruction and vitrification, production of NO_x can be decreased with the attendant decrease in off-gas system requirements. Biocatalytic nitrate destruction is applicable to a wide range of aqueous wastes with a highly variable composition. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0062

Argonne National Laboratory

Ceramicrete Stabilization Technology

Abstract
Ceramicrete™ is an ex situ stabilization technology that uses chemically bonded phosphate ceramics to stabilize low-level radioactive waste and hazardous waste containing radionuclides and heavy metals. The technology mixes phosphates with acidic solution, causing an exothermic reaction similar to that used in forming concrete. But while concrete is based on relatively weak hydrogen and van der Waals bonding, Ceramicrete uses a combination of ionic, covalent, and van der Waals bonds to stabilize contaminants.

Ceramicrete cures to create final waste forms that are analogs of naturally occurring phosphate minerals. These minerals have been shown to be relatively insoluble over geologic time scales. The final waste form is stronger than typical room temperature, hydraulic cements and performs in the manner of high-temperature fused ceramics. The technology has been evaluated in bench- and operational-scale tests on contaminated wastewater, sediment, ash, and mixed wastes.

Argonne National Laboratory (ANL) lists the following advantages of Ceramicrete technology:

- Forms a strong, dense, leach-resistant final product that is an analog of naturally occurring phosphate minerals.
- Operates at room temperature, limiting contaminant volatilization concerns.
- Is a simple and inexpensive stabilization process, low-cost fabrication using equipment similar to that in the conventional cement industry.
- Stabilizes waste containing lead, mercury, cadmium, chromium, and low-level nuclear waste.

Ceramicrete technology is not suitable for treating wastes with a high content of organic compounds. The developer states that, with the exception of calcium silicates, calcium-based aggregates reduce the quality of the final waste form. Studies on wastes with high-salt content have demonstrated that Ceramicrete is only marginally successful at retaining nitrate and chloride anions. The long-term stability of the Ceramicrete waste form is unproven. The effect of high internal radiation doses on the Ceramicrete material is unknown.

Technology Cost

Researchers state that Ceramicrete technology is a low-cost, low-tech process. The technology uses almost the same equipment as that used in the cement industry. The binder powders are more expensive (approximately 50%) than cement, but ANL scientists estimate the cost of treating low-level mixed waste is less than 50 cents per pound (D177495, p. 5).

According to ANL, the cost of the Ceramicrete binder is 10 to 12 cents per pound when applied at 70% loading. The iron-containing ferroceramicrete binder costs 3 to 4 cents per pound with the same loading ratio (D22652I, p. 7).

Operational-Scale Estimates Based on the results of a treatability study at the ANL-East in Chicago, Illinois, the laboratory prepared a cost estimate for an operational-scale Ceramicrete stabilization system. The hypothetical system would treat waste in 55-gal batches at a rate of 3 batches per shift. The capital costs for the system were estimated at $2,000,000. This estimate included the cost of equipment design and development (D20934H, p. 15).

The estimated operating costs were $6510/m^3 of treated waste. This estimate included binder costs of 85 cents per pound; the labor costs equivalent to 4 full-time technicians at $70 per hour; and the cost of the 55-gal barrels at $100 per barrel used to mix, cure, store, and dispose of the waste. The operating costs of the baseline cement stabilization process are lower at $4300/m^3 of treated waste (D20934H, p. 15).

Disposal costs at various radioactive waste management facilities in the United States range from $20/ft^3 to $1500/ft^3. ANL used an average disposal cost of $60/ft^3 of treated waste form to estimate the total disposal costs for the hypothetical Ceramicrete product. The estimated cost was $2836/m^3 of waste. According to the ANL, this figure is lower than the disposal costs for cement, which were estimated at $3700/m^3 (D20934H, p. 15).

Table 1 displays the different operating parameters of the hypothetical Ceramicrete and cement stabilization systems. Table 2 provides additional cost information about this estimate and comparison.

Information Sources

D177495, Argonne National Laboratory, 1997

D22652I, Argonne National Laboratory, undated

D20934H, U.S. DOE, undated

TABLE 1 Operating Parameters for the Ceramicrete and Cement Stabilization System Used for the Cost Estimate

Parameter	Ceramicrete	Cement
Waste form production rate	9 barrels per day 495 gal/day 1.874 m^3/day 3478 kg/day	9 barrels per day 495 gal/day 1.874 m^3/day 4994 kg/day
Waste-to-waste-form volume expansion	35%	75%
Waste throughput	1.39 m^3/day 1043 kg/day	1.07 m^3/day 749 kg/day
Waste loading	30% by weight	15% by weight
Binders to waste weight ratio	2.33	5.66
Binders to waste form weight ratio	0.7	0.85

Source: Adapted from D20934H.

TABLE 2 Cost Estimates for the Ceramicrete and Cement Stabilization Systems

Cost Factor	Ceramicrete	Cement
Labor	\$6720/day \$5.86/kg of influent waste	\$6720 per day \$8.97/kg of influent waste
Barrels	\$900/day \$0.86/kg of influent waste	\$900/day \$1.20/kg of influent waste
Binders	\$4553/day \$4.37/kg of influent waste \$1.31/kg of effluent waste form	\$425/day \$0.57/kg of influent waste \$0.09/kg of effluent waste form
Disposal	\$2118/m^3 of waste form \$3.78/kg of influent waste \$1.14/kg of effluent waste form	\$2118/m^3 of waste form \$5.29/kg of influent waste \$0.80/kg of effluent waste form
Total	\$16,115/day \$15.45/kg of influent waste	\$12,261/day \$16.37/kg of influent waste

Source: Adapted from D20934H.

T0063

Argonne National Laboratory

In-Well Sonication

Abstract
The in-well sonication technology uses an in-well ultrasonic reactor to treat groundwater in situ. The in-well sonication process decomposes toxic organic compounds from the aquifer without pumping the water to the surface. The process converts the organic contaminants into non-hazardous and/or less hazardous products in the subsurface. Researchers are currently in the process of designing a treatment train that includes this technology, in-well vapor stripping, and biodegradation to remove volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) from groundwater.

The technology is currently being evaluated using bench-scale tests for the treatment of chlorinated organics-contaminated groundwater at selected Department of Energy/Department of Defense (DOE/DOD) sites. The technology is not commercially available.

According to researchers, the combined treatment train approach has several advantages:

- Allows for in situ remediation.
- The combined technologies complement each other.
- Converts hard-to-degrade organics into more volatile organic compounds.
- No handling or disposing of water at surface required.
- Cost effective and efficient, results in shorter cleanup times to remediate a site.

The effectiveness of both sonication and biodegradation is contaminant and concentration specific. Extensive treatability studies will be required to maximize process effectiveness. Significant technical issues will have to be addressed before the technology can be used in the field.

Technology Cost
No available information.

T0064

Argonne National Laboratory

Magnetically Assisted Chemical Separation

Abstract
Argonne National Laboratory (ANL) is researching the magnetically assisted chemical separation (MACS) process for the removal of transuranic elements from aqueous acid solutions by the use of an organically coated magnetic particle that preferentially adsorbs the selected contaminant. The technology is designed to separate and concentrate transuranic compounds from high-level and transuranic wastes. The organic coating can be stripped off, allowing for the magnetic particles to be regenerated and reused. MACS has been evaluated in treatability studies on strontium using alkaline solutions. The technology also has potential applications to heavy-metal-contaminated wastes. The MACS process is still in the development stage, and has been evaluated in bench-scale tests. Research is proceeding for both in situ and ex situ applications of MACS.

ANL claims the technology is promising because radionuclides are separated from waste streams by a simple, compact, cost-effective process that does not produce large secondary waste streams. The MACS process is intended to reduce the complexity of equipment when compared to solvent extraction and ion exchange techniques, and to facilitate scale-up due to the systems inherent simplicity.

Since some MACS coatings extract both lanthanides and actinides, the particles can quickly become saturated in lanthanide-rich solutions. Decay of radionuclides adsorbed by MACS particles will cause radiolytic damage to the coating and the magnetic core. MACS particles appear to become brittle and to disperse less as radiation dosages increase, but the magnetic properties of the particles are not affected. Radiation dosage of 101 to 106 rad may cause the polymer core of the particle to unravel. The partitioning coefficient for americium decreased during prolonged exposure to strong acid solutions.

Technology Cost
No available information.

T0065

Argonne National Laboratory

Remediation Using Foam Technology

Abstract
Foams are being investigated as a technology for site remediation applications. Foams may be used to treat non-aqueous-phase liquids in the soil subsurface. Foams could be used to deliver gases, surfactants, chemicals, nutrients, and bacteria to the subsurface.

Foams are currently used by the oil industry to improve crude oil recovery, resulting in 20 to 50% higher recovery rates for oil in some applications. A field demonstration to investigate the use of foam for site remediation was planned for 1996by the U.S. Department of Energy.

Researchers see several potential advantages in the uses of foams for remediation. They include:

- Foams could be applied to both saturated and vadose zones.
- Foams could treat either scattered contaminants or contaminants in pools.

- Foams have the potential to mobilize and biodegrade the contaminants either simultaneously or sequentially.
- Foams can be generated either in situ or above ground and injected into the contaminated zone. With in situ foam generation, no volatile organic compounds would be created.
- Foams allow either aerobic or anaerobic environments to be established in the subsurface.

The stability of the foam is a critical issue that must be considered to design an efficient foam bioremediation process. If the foam lamellae break, the effective resistance of the foam to gas/liquid flow is considerably reduced in a particular subsurface area, thereby promoting local flow channeling and bypassing. Such unexpected flow channeling could significantly lower the overall remediation performance efficiency. The high pressure caused by the foam injection and the pressure drop may cause soil heaving, fracturing, and lifting.

Technology Cost
No available information.

T0066

Argonne National Laboratory

Transuranium Extraction (TRUEX) Process

Abstract
Argonne National Laboratory (ANL) has developed the transuranium extraction (TRUEX) process for the removal of actinides from acidic waste streams associated with nuclear fuel reprocessing plants. The process uses an actinide–lanthanide selective extractant, octyl (phenyl)-*N*,*N*-diisobutylcarbamoylmethylphosphine oxide (CMPO), as the key ingredient in a liquid–liquid extraction. According to the developer, the TRUEX process is capable of separating, with great efficiency, small quantities of transuranic elements from nitrate or chloride solutions typically generated in reprocessing plant operations or in plutonium production and purification operations. The technology was patented (U.S. Patent 4,548,790 and 4,574,072) by the U.S. Department of Energy.

Researchers claim TRUEX technology offers the following advantages:

- Removes trivalent, tetravalent, and hexavalent lanthanides and actinides equally well; no valence adjustment is necessary.
- Removes actinides from acidic aqueous solutions to well below the 10 nanocuries per gram (nCi/g) Nuclear Regulatory Commission (NRC) class A low-level transuranic waste requirements for disposal.
- Selective partitioning of target contaminants can be achieved during stripping procedures.

In applications of TRUEX technology to the removal of actinides from hydrochloric acid media, CMPO will extract vanadium, iron, copper, zinc, gallium, zirconium, molybdenum, tin, and lead under the same conditions under which it will extract targeted actinides. The wastes extracted by the TRUEX process will require additional treatment before they may be safely disposed.

Technology Cost
No available information.

T0067

Ariel Industries, Inc.

Ariel SST Low-Temperature Thermal Desorber

Abstract
Ariel Industries, Inc. (Ariel), has designed and manufactured the Ariel SST low-temperature thermal desorber for the ex situ treatment of soil contaminated with volatile organic compounds (VOCs) and hydrocarbons. The system is portable and is used to heat sediment to approximately 900°F, removing moisture and contaminants from the soil. The technology had been offered by Ariel industries on the commercial level, but the company is no longer in the thermal desorption business.

The vendor claims that the Ariel SST can process soils at rates up to 400% higher than an incineration process. They also state that the technology has been applied to all ranges of petroleum contaminants, including crude oil, as well as nonchlorinated hydrocarbons, chlorinated hydrocarbons, chlorinated pesticides, and polynuclear aromatic compounds.

The process has limited application for soils contaminated with polychlorinated biphenyls or any other dioxin precursor. Semivolatile compounds with boiling points greater than 800°F cannot be effectively removed from the soil in a one-pass treatment. The soil characteristic that most affects treatment is moisture content. All information in this summary is based on information provided by the vendor and has not been independently verified.

Technology Cost
In 1995, Ariel Industries, Inc. (Ariel) estimated that treating contaminated soil using its thermal desorption technology would cost between $65 and $200 per ton. This estimate stated that price estimates may not include all indirect costs associated with treatment, such as excavation, permits, and treatment of residuals. Factors listed as having a significant effect on costs include (in decreasing order of importance) the moisture content of the soil, depth to groundwater, quantity of waste, amount of debris with the waste, characteristics of the soil, target contaminant concentration, initial contaminant concentration, site preparation, waste handling and preprocessing, characteristics of the residual wastes, and weather conditions (D10021G, p. 14).

Mobilization and demobilization costs of the system were estimated to be under $50,000 in 1995 (D10021G, p. 2).

Information Source

D10021G, VISITT 4.0, 1995

T0068

Armstrong Laboratory Environics Directorate

Phase-Transfer Oxidation

Abstract
Phase-transfer oxidation is a technology for destruction of organic contaminants. It was developed to treat contaminated liquid streams using adsorption for contaminant removal and advanced oxidation processes for spent adsorbent regeneration. It was used in testing to treat the contaminated effluent from groundwater extraction technologies.

In testing, this technology was effective in treating waste streams contaminated with benzene, toluene, ethylbenzene, and xylenes (BTEX compounds). The technology is not in use at present and is not commercially available.

Technology Cost
No available information.

T0069

ARS Technologies, Inc.

Ferox

Abstract

The ARS Technologies, Inc., Ferox[SM] process is an in situ remediation technology for the treatment of chlorinated hydrocarbons, leachable heavy metals, and other contaminants. The process involves the subsurface injection and dispersion of reactive zero-valence iron powder into the saturated or unsaturated zones of a contaminated area. ARS Technologies claims that Ferox is applicable for treating the following chemicals: trichloroethene (TCE), 1,1,1-trichloroethane (TCA), carbon tetrachloride, 1,1,2,2-tetrachloroethane, lindane, aromatic azo compounds, 1,2,3-trichloropropane, tetrachloroethene (PCE), nitro aromatic compounds, 1,2-dichloroethene (DCE), vinyl chloride, 4-chlorophenol, hexachloroethane, tribromomethane, ethylene dibromide (EDB), polychlorinated biphenyls (PCBs), Freon-113, unexploded ordinances (UXO), and soluble metals (copper, nickel, lead, cadmium, arsenic, and chromium).

ARS Technologies, Inc. (formerly known as Accutech Remedial Systems), introduced the Ferox process in 1998. The process is patented under U.S. Patent 5,975,798 and is commercially available through ARS Technologies. According to the vendor, Ferox has been used at sites across the United States and overseas.

The Ferox process offers several potential advantages over conventional permeable barrier walls. For example, Ferox injection parameters may be modified to reflect the contaminant concentration heterogeneities present at most dense non-aqueous-phase liquid (DNAPL) sites. Unlike permeable walls, Ferox is not limited to the treatment of dissolved-phase contaminants and may be applied under structures. In addition, Ferox is not limited by depth and does not require the use of excessive quantities of iron powder.

The Ferox process may result in the generation of harmful daughter products. For example, the breakdown of TCE using the technology can result in increased concentrations of cis-1,2-DCE. The vendor, however, claims that bench and field tests indicate Ferox can also treat these daughter products.

Technology Cost

During a pilot-scale demonstration at a site contaminated with TCE and PCE, the Ferox process was used to treat 12 yd^3 of soil. It was estimated that the technology could be used to remediate the entire site (1500 yd^3 of soil) for a total cost of \$125,000 (about \$83/yd^3) (D18642Z, pp. 1, 2). Another estimate suggested that treatment costs could range from \$40 to \$60 per cubic yard of material treated (D186441, p. 1).

ARS Technologies is developing an injection method based on push technology, which would eliminate the need for well installations. This method would significantly reduce the time and cost of operations (D18642Z, p. 2).

Information Sources

D18642Z, ARS Technologies, Inc., 1998
D186441, ARS Technologies, Inc., 1998

T0070

ARS Technologies, Inc.

Pneumatic Fracturing

Abstract

ARS Technologies, Inc. (formerly Accutech Remedial Systems), of Highland Park, New Jersey, offers a proprietary pneumatic fracturing (PF) technology. PF is an enhancement technology

designed to increase the efficiency of other in situ technologies in low-permeability soils. The technology may be combined with soil vapor extraction (SVE) or dual-phase extraction to remove halogenated volatile organic compounds (VOCs), nonhalogenated VOCs, and semivolatile organic compounds (SVOCs) from the vadose and saturated zones of low-permeability soils and rock formations. PF may also be used to deliver microbes and nutrients to the subsurface to biodegrade the contaminants in situ.

The PF system creates a fracture network by forcing compressed gas into a formation at pressures that cause stress failure. These fractures increase the formation's permeability. Increased permeability can greatly improve contaminant mass removal rates. PF can also increase the effective area that is influenced by each extraction well and can intersect new pockets of contamination that were previously trapped in the formation. The ARS PF technology is patented and is commercially available. According to the vendor, it has been used at over 135 federal and private sites in the United States, Canada, Japan, and Belgium.

According to the developer, advantages of the PF technology include the following:

- Reduces treatment time.
- Increases the effective radii of recovery and injection wells and minimizes the number of well regions.
- Extends the use of available treatment technologies to less permeable sites.
- Increases flow rates in low-permeability geologic formations by 400 to 700%.

The PF technology also has several potential limitations. Fractures do not always propagate in the direction or to the distances expected. Fractures may open new pathways for the unwanted spread of contaminants. Pockets of low permeability may remain after fracturing. Surface heave and stress resulting from the process can create hazards for buildings or other structures at a site. If the moisture content of the contaminated media is not controlled, the formation may swell and close the fractures. PF is not applicable at sites with high natural permeabilities. Fractures will close in soils with low clay content. In addition, PF should not be used in areas of high seismic activity.

Technology Cost

The U.S. Department of Energy (DOE) states that fracturing technologies are particularly cost effective with low-permeability soils and other geologic media such as clays, shales, and tight sandstones where remediation, without some sort of permeability enhancement, is difficult or impossible. Furthermore, fracturing does not add significant up-front costs (up to a few percent) to an overall remediation system. It may also provide a significant reduction in the life-cycle costs of remediating a site because fewer wells may be required and cleanup may be accomplished more rapidly (D183771, p. 1).

Based on data from the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration, the total cost for PF extraction was estimated to be $307/kg of trichloroethene (TCE) removed. This demonstration was conducted over a 4-week period in August and September of 1992 at an industrial site in Somerville, New Jersey. The cost estimate includes expenses associated with both PF and soil vapor extraction. Major cost factors were labor (29%), capital equipment (22%), VOC emission control (19%), site preparation (11%), and residuals management (10%) (D10589F, p. v).

Using data from the SITE demonstration, the total electrical demand for operation of the system was estimated to be about 30 horsepower, primarily to operate the vacuum blower. Assuming continuous operation, electrical costs of $0.06/kWh would result in yearly expenses of about $11,750. It is assumed that the cost of fuel for larger, diesel-operated compressors would be comparable. A small additional cost could be included for lighting the system over night (for security purposes). Including on-site telephone and facsimile service, the total annual utility costs would be about $17,000 per year (D10589F, p. 19).

The SITE estimate was based on the following parameters:

- Site preparation
- Permitting/regulatory
- Capital equipment (amortized over 2 years)
- Startup
- Salaries
- Consumables and supplies
- Utilities (electricity, telephone, fax)
- Emission treatment and disposal
- Residuals storing, handling, and transport
- Demobilization (D10589F, p. 21)

The costs of analytical services and facility repair, replacement, and modification were not included in this estimate (D10589F, p. 21).

The cost of remediation is often presented in terms of dollars to achieve a final cleanup level at a site; however, that approach could not be applied in this situation because no final cleanup criteria for air or soil had been established for the SITE project. The cost estimate for TCE removal is instead based on TCE removal rates that were extrapolated from a 4-hour test to a 1-year cleanup period (D10589F, p. 14).

In 1995, PF was used with enhanced dual-phase extraction in a full-scale application at a site in central New Jersey. As a result of manufacturing activities at the site, groundwater had become contaminated with TCE. Twenty vapor extraction wells and a 500-ft^3/min vapor system were used to treat 1.5 acres to a depth of 30 ft. According to ARS Technologies, total costs were $1.1 million (D22628I, p. 1).

Pressly & Associates, Inc., an environmental consulting firm in Brookhaven, New York, researched treatment options (including PF) for a dry cleaner site contaminated with tetrachloroethene (PCE). According to the firm, a 2-acre plume exists at the site to a depth of 35 ft below ground surface (bgs) (or 30 ft below the water table). Soils at the site consist of "fine to medium sand, silt, and sand and gravel." The firm claims that capital costs for various treatment options are as follows:

- $420,000 for vertical/horizontal-well PF with iron injection
- $250,000 for vertical-well PF with iron injection
- $280,000 for a vertical/horizontal-well, high-vacuum dual-phase (HVDP) extraction system with air sparging
- $200,000 for a vertical-well HVDP extraction system with air sparging (D22625F, p. 1)

According to the U.S. Department of Defense (DOD), the cost range for PF is approximately $9 to $13 per metric ton (D10864F, pp. 4–16).

Information Sources

D10589F, U.S. EPA, 1993

D10864F, U.S. DOD, Environmental Technology Transfer Committee, 1994

D183771, U.S. DOE, 1998

D22625F, Pressly & Associates, Inc., 2001

D22628I, ARS Technologies, Inc., undated

T0071

ASTEC/SPI Division

Low-Temperature Thermal Desorption (LTTD)

Abstract

ASTEC/SPI's low-temperature thermal desorption technology is an ex situ process that treats soil contaminated with petroleum hydrocarbons including gasoline, diesel fuel, jet fuel, lubricating oils, and fuel oils by heating the soil to evaporate the contaminants.

SPI Division Level 3 and 4 LTTD systems have been designed and manufactured for thermal treatment of soils contaminated with polycyclic aromatic hydrocarbons (PAHs), including coal tars from former manufactured gas plant (MGP) sites. When equipped with acid-scrubbing systems, these LTTD systems have been utilized in treatment of soils contaminated with a wide range of chlorinated hydrocarbons including industrial solvents and degreasers, pesticides, herbicides, and polychlorinated biphenyls (PCBs).

The ex situ process is commercially available through the vendor. SPI uses four different levels of processing systems with varying maximum temperature levels. The type of contaminant found in the soil and regulatory guidelines determine which desorber is used.

For the treatment of materials containing metals and other inorganics, the addition of fly ash, portland cement, or soda ash is required for stabilization.

Technology Cost

In 1995, the vendor estimated the cost of treating soil with the low-temperature thermal desorption (LTTD) to be \$25 to \$75 per ton. Factors that have a significant effect on unit price include: contaminated soil/material volume, fuel costs, labor rates, level of regulatory involvement and oversight, compliance monitoring, health, safety and labor protection, site preparation, preprocessing, and LTTD system operating schedule (D10324S, p. 45).

The vendor states that SPI Division can assist potential customers by providing cost modeling services based on factors listed to identify estimated operating cost, processing rate, and emission prediction.

Portable and fixed LTTD systems are available. In July 1997, Mid Atlantic Recycling Technologies, Inc. (MART), opened a \$9 million permanent facility in Vineland, New Jersey, to process soil from MGP sites. The MART facility uses an ASTEC/SPI low-temperature thermal desorption unit capable of treating 45 metric tons of contaminated soil per hour. The vendor states that the facility took 7 months to construct (D18330M, p. 2).

T0072

Atomic Energy of Canada Limited (AECL)

CHEMIC Technology

Abstract

The Atomic Energy of Canada Limited (AECL) CHEMIC™ technology, formerly CHEMIC ultrafiltration process, is an ex situ technology that uses chemical pretreatment and subsequent ultrafiltration to remove trace concentrations of toxic metals and radionuclides from wastewater, contaminated groundwater, and soil leachate. In the CHEMIC process, a relatively high-molecular-weight polymer is added to the wastewater to form large, selective metal–polymer complexes at desired pH and temperature conditions. The treated solution is then processed through an ultrafiltration membrane that retains certain contaminants, while allowing other chemical elements, such as calcium and/or sodium to pass through the membrane with the filtered

water (permeate). The permeate may be discharged or recycled, depending on the goals set for metal removal.

The CHEMIC process is effective in removing cadmium, mercury, lead, iron uranium, strontium, cesium, and cobalt. The process also removes other inorganic and organic materials present as suspended or colloidal solids.

According to the technology developer, the CHEMIC process has a number of advantages: the system can be readily turned on and off without a long transient time; modular construction yields a large range of flow rate options and portability; the process is generic and can be adapted to treat waste solutions containing a variety of radioactive and hazardous contaminants; the process operates in a closed-loop configuration; and it can be fully automated for 24-hr operation.

The CHEMIC process does not effectively remove arsenic from solution. Removal efficiency for arsenic is only about 10 to 35%. Also, the ultrafiltration membranes used in the process can become fouled due to compaction of the membrane, physical aging by extended operation, and plugging of the membrane pores by particles.

The CHEMIC technology has been tested at the bench-, pilot-, and field-scale levels as part of the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) Emerging Technology Program in 1989 and in the early 1990s. It has also been evaluated by the U.S. Department of Energy (DOE). According to the technology developer, the CHEMIC technology has been fully demonstrated for the treatment of contaminated groundwater.

Technology Cost

The technology developer, Atomic Energy of Canada Limited (AECL), has compiled cost estimates (in 1994 U.S. dollars) for the CHEMIC process based on treatment of a simulated waste solution contaminated with metals (cadmium and lead at feed concentrations from 1 to 5 mg/liter) and strontium-90 [from 1000 to 2000 becquerel per liter (Bq/liter)]. The target treatment level is <0.014 mg/liter lead, <0.02 mg/liter cadmium, and <10 Bq/liter strontium-90. See Table 1 for estimates associated with this cost analysis. The AECL analysis indicated that costs of the CHEMIC process compared favorably with the estimated costs for treatment using reverse osmosis or fixed-bed ion exchange.

The components considered in the cost analysis consist of pretreatment and treatment of the waste. Capital costs increase linearly with treatment capacity. However, annual operating and maintenance costs decrease slightly as treatment capacity increases (D14793X, pp. 10.6.11–10.6.12). Capital costs do not include site preparation, building, and capital recovery. Operating and maintenance costs were estimated on the assumption that the process would be operated 24 hours per day, 350 days per year (operating costs do not include taxes, insurance, and patents) (D14793X, p. 10.6.13). Secondary disposal costs were the largest component of the operating and maintenance cost and were estimated to be about $2220/m^3$ ($63/ft^3$) due to radioactivity (D14793X, p. 10.6.12).

TABLE 1 Capital and Annual Operating and Maintenance Costs for the CHEMIC Ultrafiltration Process

	Treatment Capacity	
Process System	578 liters/min (150 gpm)	1,136 liters/min (300 gpm)
Capital cost	$769,000	$1,378.000
Volume reduction factor	900	900
Operating and maintenance cost (including disposal)	$713,000 ($9.43/1,000 gal)	$1,364,000 ($9.02/1,000 gal)
Total	$1,482 ,000	$2,742,000

Source: Adapted from Table 7, D14793X, p. 10.6.13.

Based on data obtained during testing for the U.S. Department of Energy (DOE) in 1992, cost estimates were prepared. These estimates used a 2-gallon-per-minute (gpm) pilot plant as a baseline case, and projected the costs of a full-scale 300-gpm facility. It was estimated that the installed costs would be $(US)275,000 for the 2-gpm system, and $4 million for the 300-gpm system. Annual operating costs were estimated to be $368,000 and $4 million for the 2-gpm, and 300-gpm systems, respectively. Annual secondary waste disposal costs were estimated to be $50,000 (2-gpm plant) and $8 million (300-gpm plant) (D152136, p. x).

At the conclusion of DOE testing in 1996, AECL developed a cost estimate for the treatment of contaminated soil using the technology as part of a treatment train. The combined cost of soil leaching and leachate treatment was estimated to be $340 per ton of treated soil (DOE/Fernald soil). This estimate included all operating and capital depreciation costs for a plant life of 5 years. The cost estimate also assumed the reuse of the recovered uranium from the soil treatment at an existing Canadian facility (D17560U, p. 68).

Information Sources

D14793X, Atomic Energy of Canada, Ltd., 1995

D152136, U.S. DOE, 1992

D17560U, Federal Energy Technology Center, 1997

T0073

ATW Incorporated

Impoundment Detoxifier

Abstract

Impoundment Detoxifier™ is a commercially available proprietary technology for the treatment of impoundments containing chemical, biological, or radioactive sludges or semisolid wastes. The vendor claims that Impoundment Detoxifier has successfully treated wastes from field and refinery operations, chemical operations, and uranium operations. All information is from the vendor and has not been independently verified.

Technology Cost

No available information.

T0074

ATW, Inc.

RAD-CAST

Abstract

RAD-CAST™ is an ex situ technology that is designed to process mixed waste from disposal sites or point of generation using centrifugation and solidification materials. The waste product is contained within a liner. The liner and centrifuged sediment is then placed in retrievable storage. According to the vendor, this three-step technology treats low-level radioactive-contaminated residues, soils, or dry activated wastes.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0075

B & S Research, Inc.

B & S Achieve-B & S Industrial

Abstract
The B & S Research, Inc., B & S Achieve-B & S Industrial™ technology uses microorganisms (B & S Industrial) with emulsifier and nutrients (B & S Achieve) to treat contaminated soil and water. According to the technology developer, the technology degrades hydrocarbons, chlorinated solvents, polychlorinated biphenyls (PCBs), fertilizers, pesticides, and other hazardous organic compounds.

The developer asserts that the technology is applicable to soil (in situ and ex situ), nonmunicipal sludge, solid (e.g., slag), and natural sediment (in situ and potentially ex situ).

According to the developer, the technology has been applied in the following industries: agriculture, dry cleaning, gasoline/service station, herbicide manufacturing/use, machine shops, pesticide manufacturing/use, petroleum refining and reuse, and wood preserving. The developer further claims that the technology has potential applications in treating contaminants in these industries: municipal landfilling, munitions manufacturing, plastics manufacturing, pulp and paper industrial applications, and organic chemical manufacturing.

According to the technology developer, the technology has the following limitations:

- Cannot treat heavy metals or nonbiodegradable contaminants.
- Has optimum working pH range of 5 to 8.

Technology Cost
The estimated cost range for using the B & S Achieve-B & S Industrial technology is \$8.00 to \$25.00/yd^3 (D10023I, p. 29).

Among the factors that affect the cost of the technology are (D10023I, p. 29):

- Contamination depth
- Initial contaminant concentration
- Target contaminant concentration
- Soil characteristics
- Waste quantity
- Site preparation
- Moisture content of soil
- Amount of debris with waste
- Depth to groundwater
- Residual waste characteristics

Information Source

D10023I, VISITT 4.0

T0076

B & W Services, Inc.

Cyclone Furnace Vitrification

Abstract
B & W Services, Inc. (B & W, formerly Babcock & Wilcox Nuclear Environmental Services, Inc.), has developed cyclone furnace vitrification for the ex situ treatment of wastes and contaminated soils. The B & W cyclone furnace is designed to combust high-inorganic (high-ash) coals. Through cofiring, the cyclone furnace can also accommodate highly contaminated wastes containing heavy metals and organics in soil or sludge. High heat release rates of 45,000 Btu (13.2 kWh) per foot of coal ensure the high temperatures needed for organics combustion are achieved. Wastes leave the cyclone furnace in the form of an inert ash. The B & W cyclone furnace technology is a well-established design for coal combustion.

The B & W cyclone furnace can be used to treat soils, sludges, liquids, and slurries contaminated with hazardous inorganic and organic constituents, low-level radioactive solid wastes, or a combination of the two. Particulate matter from the waste stream is retained along the walls of the furnace by the swirling action of the combustion air and incorporated into a molten slag layer. Organic material in the soil is vaporized or combusted in the molten slag.

Pretreatment may be necessary to render wastes into a form that can be processed. Fly ash requires recycling through the process to maximize percentage of metals retained in the melt.

Technology Cost
Based on data collected during the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program demonstration in 1992, a cost estimate was

TABLE 1 Summary of Economic Analysis Estimates

	Online Factor					
	60% Online		70% Online		80% Online	
Cost Category	($/ton)	($/metric ton)	($/ton)	($/metric ton)	($/ton)	($/metric ton)
Site preparation	31.37	34.58	31.37	34.58	31.37	34.58
Permitting	0	0	0	0	0	0
Equipment	43.83	48.31	38.52	42.46	34.53	38.06
Startup and fixed	58.67	64.67	58.94	64.97	59.48	65.56
Labor	219.95	242.45	188.53	207.82	164.96	181.84
Consumables and supplies	159.98	176.35	159.85	176.20	159.74	176.08
Effluent treatment	0	0	0	0	0	0
Residuals and wastes shipping and handling	0	0	0	0	0	0
Analytical services	0	0	0	0	0	0
Facility modifications and maintenance	1.24	1.37	1.06	1.17	0.93	1.02
Demobilization	13.83	15.24	13.83	15.24	13.83	15.24
Total cost	528.88	582.99	492.09	542.44	464.84	512.40

Source: Adapted from D123331.

prepared. The cost of treating 20,000 tons of contaminated soil in a facility operating at a rate of 3.3 tons/hr is approximately \$528.88/ton for an online factor of 60%, \$492.09/ton for an online factor of 70%, and \$464.84/ton. This estimate is based on the treatment of 3 tons of contaminated soil using a pilot-level system during the SITE demonstration (D123331, pp. 15–24). This cost estimate is summarized in Table 1.

In 1996, costs of cyclone vitrification were estimated at \$465 to \$600/metric ton, with an average cost of \$530/metric ton. Capital costs were estimated at \$35 to \$50/metric ton. Costs would be higher for applications involving remote operations (D136027).

Information Sources

D123331, U.S. EPA, 1992
D136027, Environment Canada, 1996

T0077

B & W Services, Inc.

EcoSafe Soil Washing

Abstract
EcoSafe™ soil washing is an ex situ technology that treats soils contaminated with radioactive materials. The soil washing process eventually separates contaminated soils into a coarse size fraction and a fine size fraction that are the clean and contaminated portions, respectively. Two screening and washing steps combined with two dewatering steps comprise the washing process. According to the vendor, the technology cannot be used for soils that contain more than 30% silt or clay.

The technology, developed by B & W Nuclear Environmental Services, Inc. (now B & W Services, Inc.), has been demonstrated at the bench- and pilot-scale levels. The company has abandoned the technology since a cost–benefit analysis proved it to be too expensive to implement. It is not commercially available.

Technology Cost
The vendor originally estimated the treatment cost of the EcoSafe™ soil washing technology to be between \$6 and \$12/ft^3 of soil. According to the vendor, a treatability study was conducted that cost \$70,000,000 to treat 2 tons of uranium-contaminated soil (D10024J, p. 13).

A later cost–benefit analysis determined that the technology was too expensive to implement (personal communication, Chuck Peach, Babcock & Wilcox Nuclear Environmental Services, Inc., February, 1997).

Information Source

D10024J, VISITT 4.0, 1995

T0078

Barr Engineering Company

Co-Burning Technology

Abstract
Co-burning is a commercially available, ex situ technology for the treatment of nonhazardous tar and tar-contaminated soils from former manufactured gas plant (MGP) sites. The process burns MGP waste with coal in existing utility boilers at coal-fired power plants.

The amount of ash generated by coal-fired power plant furnaces may increase significantly with the addition of soil. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0079

Basys Technologies

Basys Biofilter

Abstract
Basys Technologies biofilters are designed to treat process emissions containing volatile organic compounds (VOC). According to the vendor, the VOCs are eliminated by contacting the contaminated vapor streams with natural organic media that supports the growth of various bacteria that digest the contaminants.

This technology is currently commercially available.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0080

Battelle Memorial Institute

Electroacoustic Dewatering

Abstract
The in situ electroacoustic dewatering (EAD) technology is a novel separation process designed for the removal of organics and heavy metals from contaminated soils. The patented in situ EAD technology treats contaminants by applying current directly to the contaminated soil to simultaneously produce electrical and acoustical fields. The simultaneous effect of these fields facilitates the transport of cations through the soils that carry water with them. Use of the combined fields has been found to be more effective than either of the fields operating alone. The technology is not commercially developed.

The EAD technology works most effectively on clay-type soils where the hydraulic permeability is small. Results indicate that the EAD technology can remove inorganic contaminants such as zinc and cadmium from clay soils. Soil contaminants may be cations, such as cadmium, chromium, and lead, or anions, such as cyanide, chromate, and dichromate.

Another possible application for the technology is unclogging recovery wells by opening soil pores near the well inlets.

The EAD technology is only marginally effective for hydrocarbon removal.

Technology Cost
Electrical energy consumption for the process is roughly estimated to be in the range of 0.3 to 0.4 kWh/gal. Thus, power costs would be about $0.015 to $0.02 per gallon (D13622B, pp. 372–372).

Information Source

D13622B, Hinchee et al., 1993

T0081

Battelle Columbus

Liquid–Liquid Extraction of Metals (LLX)

Abstract
According to the vendor, liquid–liquid extraction (LLX) provides recovery, separation, purification, and concentration of metals in one unit process. By use of the proper extractant, metals can be reduced in process or waste streams to the low parts per million (ppm) level. The metals concentrated by the process can often be reused. When appropriate, specific metals can be recovered selectively in the presence of other metals or process stream components. Alternatively, broad-spectrum metal recovery is achievable with the properly selected extractant or process.

This technology is commercially available. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0082

Battelle Memorial Institute

UNIDEMP

Abstract
The Universal Demercurization Process, or UNIDEMP™, is an ex situ process for removing mercury from a variety of solid and aqueous mercury waste streams such as metals, concrete, soils, asbestos, plastic, and cable as well as amalgams and mercury compounds. The process can also treat polychlorinated biphenyls (PCBs) and halogenated organics. UNIDEMP is a mobile system that volatizes and condenses mercury in a countercurrent rotating furnace at temperatures from 550 to 650°C. Celsius.

UNIDEMP was developed in Europe and is based on 10 years of experience with the demercurization of mercury-containing batteries. The equivalent process for batteries, DEBATOX, has been field tested in Europe. This technology is ready for commercial application.

Advantages of UNIDEMP include the following:

- The process converts mercury-contaminated hazardous waste to mercury-free recyclable products (no mercury-containing secondary waste is generated).
- The process is operated as a closed system.
- Available state-of-the-art industrial equipment is used to reduce cost.
- The method incorporates experience from industrial pyrometallurgical processes.
- Total energy consumption and costs are very low.
- Ninety percent of the energy consumption is primary energy.
- The method involves simple operation and process control.
- It provides for complete flue gas and wastewater treatment.
- There is no manual handling and easy working conditions are employed.
- There are minimum personnel exposure and very low worker risks.

Technology Cost

The estimated unit costs for processing nonradioactive materials by UNIDEMP are estimated to be in the range of $300 to $600 (1996 dollars) per metric ton, based on capital and operating costs and plant amortization for a commercial-scale plant (approximately 5000 metric tons per year throughput). These parameters are for DEBATOX (the equivalent process for mercury-containing batteries) plants scheduled to become operational in 1997 (D14642J, p. 6). These costs are nearly 80 to 90% lower than the unit costs of processing by other chemical, physical, and thermal mercury treatment processes for similar waste materials and given requirements (D14641I, pp. 6, 7).

Information Sources

D14641I, Kohli et al., 1996
D14642J, Kohli et al., 1996

T0083

Battelle Pacific Northwest Laboratory

Compact Processing Unit (CPU)

Abstract

The compact processing unit (CPU) is a waste treatment technology designed for the treatment of radioactive process liquids, sludges, and slurries. It is designed to incorporate waste treatment modules that could potentially have application to all Department of Energy (DOE) radioactive liquid tank wastes. The CPU waste treatment hardware system is applicable to high-level, low-level, and transuranic chemical separation technologies. The prototype CPU includes a process module of cesium-specific ion exchange resin columns that are selective to cesium ions.

Pacific Northwest Laboratories developed the compact or modular processing unit concept in 1991. Westinghouse Hanford Company (WHC) performed a detailed feasibility study with further development in 1992. Individual modules are expected to be manufactured off-site by commercial vendors.

All information is from the vendor and has not been independently verified.

Technology Cost

A cost estimate performed by the Westinghouse Hanford Company (WHC) showed that the development of this technology, including safety, environmental documentation, and construction of the prototype system, should cost $32 million. The estimated annual operating cost of this technology is estimated to be $9.5 million/year of operation.

Information Source

D167797, vendor literature

T0084

Battelle Pacific Northwest Laboratories

Gas-Phase Corona Reactor

Abstract

The gas-phase corona reactor (GPCR) uses high-voltage alternating-current fields to create a nonequilibrium plasma that destroys volatile organic compounds (VOCs) in off-gas products.

This technology is currently the focus of pilot-scale experiments by Battelle Pacific Northwest Laboratories (PNL), which has shown GPCR has the potential to destroy trichloroethylene and naphthalene with greater than 99.9% efficiency. Tests with other pollutants, including biological and chemical warfare agents, have been undertaken. Capital costs are projected to be lower than many baseline technologies.

The GPCR has only been applied as an off-gas treatment, although it has been noted that the technology may have applications with liquid wastes. Chlorinated VOCs require a scrubber to neutralize acid gas emissions. Research is under way to fully characterize reactions in the GPCR and to maximize performance. There have been no full-scale studies on the process to this point.

Technology Cost

Following field testing at the U.S. Department of Energy Savannah River facility, additional studies using a dielectric pellet material were found to allow treatment rates to rise by a factor of 5.2. This information was used, along with test data, to provide a cost estimation (D116256, p. 3). Cummings and Booth in 1996 used this information, along with other data supplied by Battelle PNL, to estimate costs for different flow rates and organics concentrations using a GPCR. These results are summarized in Table 1.

The estimate is based on the following conditions:

- Target contaminants are 70% perchloroethane, 30% trichloroethane.
- Total equipment cost (TEC) include equipment purchase, shipping, taxes, and freight.
- Total capital cost (TCC) includes TEC, building, site preparation, and indirect costs.
- Total capital required (TCR) includes TCC, design, inspection, project management, construction management, management reserve, and contingency.
- Total operating labor cost (TOLC) includes instrument calibrations, monthly sampling and analysis, reporting, and supervisory labor supplied by the vendor.
- Total maintenance cost (TMC) includes reactor replacement every 5 years, fuses, gaskets, annual parts, and annual labor.
- Annual electricity cost (AEC) is 8 cents per kilowatt hour.
- Annual capital cost is for an interest rate of 2.8% over a 10-year loan.
- Unit costs given in terms of dollars per pound over a 10-year operation.
- Estimations are given for a variety of flow rates and concentrations (D12104Q, pp. 55–56).

TABLE 1 Summary of Estimated Costs in Dollars/Ton (0.90718 metric ton) for Various Feed Rates and Influent Concentrations for Gas-Phase Corona Reactor Treatment of Volatile Organic Compounds

Maximum Flow Rate	100 ft^3/min		500 ft^3/min	
Influent concentration	50	1,000	50	1,000
Number of reactors	1	1	4	4
TEC	27,310	30,509	69,493	87,549
TCC	69,415	73,541	123,831	147,123
TCR	128,417	136,051	229,086	272,177
TOLC	15,500	15,600	15,600	15,600
TMC	2,166	2,873	6,253	8,609
AEC	4,650	8,198	24,756	40,985
Unit Costs	34	2	13	1

Source: Adapted from D12104Q.

Information Sources

D116256, Heath and Birmingham, 1995
D12104Q, Cummings and Booth, 1996

T0085

Battelle Pacific Northwest Laboratory

Subsurface Lithoautotrophic Microbial Ecosystem (SLiME)

Abstract
Subsurface lithoautotrophic microbial ecosystem (SLiME) is a preemerging technology being investigated for its potential in transforming or immobilizing hazardous and radioactive waste plumes in deep strata. Battelle Pacific Northwest Laboratory will be testing SLiME's effectiveness at breaking down different contaminants.

Battelle Pacific Northwest Laboratory Researchers discovered microbial communities in deep crystalline rock aquifers within the Columbia River Basalt (CRB) Group at a U.S. Department of Energy site in Hanford, Washington. While most subsurface microbial communities depend upon photosynthesis for energy (directly or indirectly), SLiME was found to derive energy from hydrogen that comes from reactions between water and basalt. SLiME could potentially be used in deep strata because they are preadapted to these conditions.

Technology Cost
No available information.

T0086

Pacific Northwest Laboratory

Vegetable Oil Remediation

Abstract
The use of vegetable oil for remediation of organic contaminants in an aquifer or unsaturated zone has been studied at Pacific Northwest Laboratory. The oil strips organic compounds from the aqueous phase or particulate matter and is then pumped out for recovery. In addition, the oil can be used as a carbon source by microorganisms, hence encouraging in situ bioremediation. The technology has not proceeded beyond bench-scale testing and is not commercially available.

Oil, when mixed with water, forms small droplets. In a soil matrix these droplets become trapped on the soil particles and form a sort of organic filter. Organics present as solutes in the groundwater will partition into the oil as the contaminant plume passes the "filter," depending on the relative affinity of the contaminant for the oil. Oil concentrates or strips the organic contaminants, such that the concentration of the contaminants is reduced and such contaminants are available to be either pumped out of the subsurface or metabolized by microorganisms. Organic compounds typically found as contaminants of groundwater are present as aqueous solutes or as immiscible liquids (in a separate phase).

Vegetable oil's usefulness in bioremediation is as a carbon, or nutrient, source for microorganisms. By providing the microorganisms with this nutrient source, their ability to degrade contaminants is magnified. Vegetable oil differs from most carbon sources in that it is not soluble in water. Other characteristics that make vegetable oil a good candidate for use as a carbon source to stimulate microorganisms that will degrade nitrate include:

- High energy content.
- Readily degradable by a large number of microorganisms.
- It is a liquid that can be injected into the soil or aquifer matrix.
- Possibly most importantly, it is insoluble in water and should not move with the water, therefore allowing it to act as a filter.
- Application methods may be adapted to deliver microorganisms, enzymes, nutrients, and electron donors to subsurface zones in order to stimulate or enhance denitrification.

Effluent waters from denitrification reactors, while free of nitrate, may have other water quality problems. During bench-scale testing, it was found that process effluent contained high chemical oxygen demand (COD), total suspended solids (TSS), and turbidity. Dissolved oxygen (DO) levels were low, and odor was caused by the presence of measurable amounts of hydrogen sulfide.

Technology Cost

The basic material used by this technology, vegetable oil, is inexpensive (D14820J, p. 2). Column data suggest that 1 ounce of oil would remove 10 parts per million (ppm) nitrate from approximately 195 gal of oxygenated water. Based on this efficiency of nitrate removal, a dollar's worth of oil (about 0.4 gal) should remove 10 ppm nitrate from about 10,600 gal of water. Theoretically, under anaerobic conditions, 1 ounce of oil should remove 10 ppm nitrate from about 650 gal of water (D179424, p. 82).

Information Sources

D14820J, Hunter et al., 1994
D179424, Hunter and Follett, 1995

T0087

Pacific Northwest National Laboratory

Liquid Corona

Abstract

Liquid corona is a technology used to treat liquid streams contaminated with hazardous organic compounds. The technology uses a high-voltage direct-current discharge positioned between an electrode in air and a liquid surface. Although the technology has been demonstrated in bench-scale studies, it is not yet available commercially.

Laboratory research has demonstrated that the liquid corona technology can treat a variety of wastewater contaminants such as carbon tetrachloride, metal ion chelators, and industrial dyes. The technology successfully reduced initial organic contaminant concentrations (by more than 99%) for the following contaminants after exposure to corona discharge: trichloroethylene (TCE), ethylene-diamine-tetraacetic acid (EDTA), and benzoic acid. Additionally, liquid corona has demonstrated removal success with carbon tetrachloride, pentachlorophenol, and perchloroethylene.

The liquid corona technology can treat hazardous or toxic organic contaminants in water. When the technology is used to treat water, the plasma generates very reactive species that react with the contaminants in the water. The technology developer claims that the technology is very effective on materials that are recalcitrant to other methods of destruction.

The technology developer asserts that the advantages of the liquid corona technology include:

- Water in the vapor space produces highly reactive species that enhance contaminant destruction.
- Reactive chemicals such as peroxide and ozone are unnecessary.
- The technology treats contaminants that are not effectively treated by advanced oxidation technologies.

Technology Cost

Based on data from a laboratory-scale study, preliminary costs for capital and operating and maintenance (O&M) expenses were estimated for a corona discharge reactor that could treat water containing 4200 parts per billion (ppb) of carbon tetrachloride (with a flow rate of 25 gpm). The liquid corona technology's O&M costs were 50% lower than those of the air-stripping/granular activated carbon (GAC) process and were 74% lower than those of the ultraviolet(UV)/oxidation process (D11866L, pp. 1030–1031).

When the liquid corona technology was used to treat water contaminated with 40 parts per million (ppm) pentachlorophenol (PCP), the electrical costs ranged from \$1.00 to \$2.00. In comparison, the published costs for using the UV/hydrogen peroxide advanced oxidation technology to treat water contaminated with 10 ppm PCP ranged from \$1.25 to \$3.00 per 1000 gal of waste treated (D14691S, p. 1).

Information Sources

D11866L, Caley et al., 1997

D14691S, Pacific Northwest National Laboratory

T0088

Battelle Pacific Northwest Laboratories

Terra-Vit Vitrification Technology

Abstract

Pacific Northwest Laboratories (PNL) developed the Terra-Vit™ vitrification system for the ex situ treatment of hazardous, radioactive, and mixed wastes. The technology uses a joule-heated melter (meaning heat is provided by passing an electric current through the melt) to destroy organic contaminants in the waste and to melt inorganic contaminants that cool to form nonleachable glass. The technology is commercially available.

PNL claims that Terra-Vit has the following advantages:

- It is cost competitive.
- A variety of wastes can be processed using the same unit.
- In some cases, processed wastes may be sold for other uses.

Wastes with water content greater than 85% increase the energy costs of the process. Some problems have been noted with phase separations in the final waste form. The technology cannot treat gases or iodine. Mercury is difficult to incorporate. There are concentration limits for some elements in a silicate glass final waste form. Phosphate glass final waste forms can incorporate greater concentrations of some metal oxides, chlorine salts, and mercury in some cases.

Technology Cost

In 1995, Battelle PNL estimated that the cost of processing wastes using the Terra-Vit vitrification system would range from \$50 to \$300 per wet ton. This estimate may not include all indirect processing costs associated with treatment. Factors that can impact costs are (in decreasing order of importance): labor rates, utility/fuel rates, quantity of waste, moisture content of the soil, characteristics of the soil, waste handling and preprocessing, and site preparation costs (D10028N, p. 26).

In 1996, PNL estimated that a 100-ton-per-day facility using $0.06/kWh of electricity would cost approximately $125 per ton. Wastes with some energy content can be processed at much lower costs. For example, ash with high carbon content may cost less than $50 per ton to process. There is also the possibility that the waste form produced could be sold as construction materials or for some other application to offset processing costs (D126034).

Terra-Vit was evaluated in a pilot-scale treatability study at the Recomp of Washington site in Ferndale, Washington. During this study, Terra-Vit was used to process 2 tons of municipal incinerator ash containing barium, cadmium, and lead. Treatment costs were reported to be $52 per ton (D10028N, p. 11; D213445).

Most of the cost data for vitrification technologies are estimates based on pilot-scale operations. Such data are suspect because they are based more on extrapolation than on experience. Such estimates are difficult to compare because the assumptions on which they are based may vary widely (D18248T, p. 55).

Many site-specific characteristics have an impact on vitrification technologies. One critical aspect of any thermal technology is the water content of the waste. Water dilutes feed material, requires energy to drive off, and physically limits the feed rate of waste. Feed preparation is another variable, which differs with the technology and with site-specific characteristics. Many estimates do not take into account site preparation and waste disposal costs. Only complete treatment life-cycle assessments can provide reliable comparison data, and such studies are, by definition, highly site and waste specific (D18248T, p. 55).

Information Sources

D10028N, VISITT 4.0, 1995

D126034, Pacific Northwest Laboratories, 1996

D18248T, Sigmon and Skorska, 1998

D213445, U.S. EPA, undated

T0089

Bearehaven Reclamation, Inc.

In Situ Bioremediation

Abstract

Bearehaven Reclamation, Inc. (Bearehaven), in situ bioremediation is a proprietary technology for the treatment of organic contaminants. According to the vendor, the process can readily remediate trichloroethylene (TCE), polychlorinated biphenyls (PCBs), diesel fuel, and other more complex organic compounds in soil, water, sludge, and landfills.

The technology uses a mixture of indigenous and proprietary microorganisms and off-the-shelf equipment. The vendor claims that due to aerobic treatment, potentially dangerous methane gas is not produced.

The technology is not applicable to metallic wastes, building and construction materials, and insoluble inorganic compounds. In liquid phases, lower temperatures decrease reactivity and increase the time required for complete bioremediation. All information is from the vendor and has not been independently verified.

This technology is not commercially available, and there is no evidence that it has been tested.

Technology Cost
In 1995, the vendor estimated the cost of remediation using this technology to be between $4 and $6/yd^3 of waste treated. Initial and target contaminant concentration and depth of contamination were cited as having the most significant effect on price (D10029O, p. 22).

Information Source

D10029O, VISITT, July 1995

T0090

Beco Engineering Company

Alka/Sorb

Abstract
The Alka/Sorb air pollution control system is designed to remove dioxin, furans, toxic metals, acid gases, and particulates from industrial and medical incinerator off-gas. The Alka/Sorb system consists of a dry treatment/wet scrubbing process during which incinerator off-gas is cooled, contacted with an alkaline powder, injected with a sorbent, filtered by a baghouse and then wet-scrubbed for final removal of trace acid gases. Two central parts of the Alka/Sorb system include a wet-acid scrubber and a patented sorbent called Diox-Blok, which prevents the formation of dioxins and furans in air emissions.

According to the vendor, Alka/Sorb is capable of meeting the most stringent state standards for all emissions, including dioxin/furans and mercury. The vendor also states that Alka/Sorb is one of the few air pollution control systems capable of meeting stringent European Union (EU) emission standards.

In order to treat gases exceeding 500°F, an upstream gas cooling device is a necessary add-on to the Alka/Sorb system. Also, a secondary scrubber is required to process exhaust gases containing a high load of sulfur oxides.

Technology Cost
According to vendor-supplied information, Alka/Sorb scrubbing units typically range in price from $200,000 to $300,000 for every 1000 lb per hour of waste incineration capacity (D10030H, p. 2).

Information Source

D10030H, VISITT, 1993

T0091

BenCHEM, Inc.

Soil Washing Technology

Abstract
BenCHEM, Inc., developed a bench-scale, noncommercial, aqueous-based soil washing technology that operates at ambient temperature and pressure to extract heavy metals from soil. The portable system is a multistage elutriation (the separation of particles according to aerodynamic diameter by allowing them to settle through a moving airstream) system in which contaminated soils flow countercurrently to soil washing agents.

The BenCHEM soil washing system successfully treats inorganic mining ores and ore processing tailing wastes. The technology has also been successfully applied to petroleum-contaminated soils containing tetraethyl lead.

The BenCHEM system can treat some organics using the aqueous medium but has difficulty treating organometallic compounds with high molecular weights.

Technology Cost
No available information.

T0092

Billings and Associates

Subsurface Volatilization and Ventilation System

Abstract
The subsurface volatilization and ventilation system (SVVS) is a commercially available integrated technology that includes soil vapor extraction/air sparging and in situ bioremediation for the treatment of subsurface contamination in soil and groundwater. SVVS has been used at over 130 underground storage tank (UST) sites and has been demonstrated at a site contaminated with volatile organic compounds (VOCs) and chlorinated hydrocarbons under the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) Program. The technology uses vapor extraction to remove volatile components and biostimulation to remove the less volatile components. Vapor extraction is typically the dominant mechanism at the beginning of treatment, while the bioremediation mechanism may dominate in the later stages.

SVVS was evaluated at the Electro-Voice Superfund site in Buchanan, Michigan, as part of the SITE Demonstration Program. The results of this demonstration indicated 80% reductions in the seven target VOCs. SVVS was also applied at four sites with leaking underground storage tanks in the Albuquerque/Belen Basin and at gasoline spills and leaks in the Metropolitan Rio Grande Conservancy District and at Southwest Distributing.

According to Billings and Associates, Inc., advantages of SVVS include the following:

- Positive and negative air flow and pressure can be shifted and manipulated to remediate different locations at the site.
- Negative pressure levels can be altered to prevent the escape of vapors.
- Can enhance bioremediation, thereby decreasing the remediation time.
- May contain contaminant plumes through its unique vacuum and air injection techniques.
- Rapid installation.
- Fast and cost effective because all phases of contamination are treated simultaneously.
- Groundwater recontamination, as might be seen with traditional pump-and-treat systems, does not occur when all phases are treated together.
- Contaminants are destroyed by bioremediation.

Limitations of the SVVS technology include the following:

- To date, limited to organic wastes.
- Large subsurface debris can inhibit the process.
- Water table should be more than several feet from the land surface.
- Humic substances in the soil can interfere with the process.

- High concentrations of iron or toxic metals can cause problems.
- Toxic compounds can be detrimental to the indigenous soil microbes.

Technology Cost

The average cost for remediating a typical gas station site is between \$200,000 and \$400,000, depending on site-specific conditions (D10869K, p. 3). The estimated cost for remediating 21,300 yd^3 (16,294.5 m^3) of vadose zone soils over 3 years at the Electro-Voice Superfund site in Michigan would be \$220,737, or \$10.36/yd^3 (\$13.55/m^3 (D10192Y, p. 46). This estimate does not include effluent treatment and disposal, travel, and employee expenses (D10192Y, p. 43). It does include technology-specific site preparation; analytical services; residuals and waste shipping, handling, and storage; labor; capital equipment; and utilities. Sand chimneys were necessary at the Electro-Voice site due to highly stratified soil, but their cost is not included here (D10192Y, p. 39).

According to the vendor, the following factors can have a significant impact on the cost of remediation. The most important factors are the depth of the groundwater and the contaminant concentration. In addition, soil characteristics, site preparation, and labor rates are important (D10033K, p. 36).

Information Sources

D10192Y, U.S. EPA, August 1995

D10869K, King Communication, June 1994

D10033K, U.S. EPA, 1995

T0093

Bio Solutions, Inc.

Soil Slurry-Sequencing Batch Reactor

Abstract

Soil slurry-sequencing batch reactor (SS-SBR) is a technology for the biological treatment of organic contaminants in soil. The technology has been evaluated in full-scale field tests but is not commercially available. The SS-SBR system consists of a set of tanks operated on a fill-and-draw basis. Each tank is filled during a discrete period of time and operated as a batch reactor. According to the vendor, reaction times are on the order of days.

The SS-SBR system can treat a wide range of contaminants, including nonhalogenated semivolatile compounds, polynuclear aromatic (PNA) compounds, and benzene, toluene, ethylbenzene, and xylenes (BTEX). According to the vendor, the system has the advantage of control and reliability with readily adjustable soil/water ratios, nutrient amendments, and co-substrate additions.

SS-SBR systems are not applicable to the treatment of inorganics and nonbiodegradable compounds. Particle size is critical and a prescreening process is necessary. The percent solids in the slurries must be maintained between 20 and 50%. Finally, dewatering of the slurry is typically required after biological treatment.

Technology Cost

According to the vendor, the estimated price of remediation using a soil slurry-sequencing batch reactor system was \$50 to \$110/m^3 of waste treated in 1995. Costs are usually 1.5 to 2 times less than excavation and inceration. The quantity of waste and initial contaminant concentration were cited as the most significant factors effecting price (D10036N, p. 15; D15328G, p. 7).

The total cost of bench-scale testing on a Department of Defense landfill was $100/m^3 (D10036N, p. 10).

Information Sources

D10036N, VISITT, July 1995

D15328G, University of Waterloo, date unknown

T0094

Biobarrier — General

Abstract
Biobarrier technologies use in situ bacterial growth to produce a barrier. This barrier consists of the bacteria themselves or the biopolymers produced by the bacteria as part of their cell walls. The barriers reduce the hydraulic conductivity of a contaminant plume thus allowing for its containment and/or control. This technology was designed to contain subsurface contaminants including landfill and underground injection leaks and spills from storage, treatment, and process facilities.

Biobarriers work by containing contaminants and therefore must be used in conjunction with a remediation technology for contaminant treatment.

Technology Cost
No available information.

T0095

Bio-Electrics, Incorporated

Electrofrac Detoxification System

Abstract
Bio-Electrics, Incorporated, has developed the Electrofrac Detoxification System to treat hazardous contaminants in soil. The system, which was developed from gasification research, uses electrodes placed in soil to heat the site. There are potential applications of this technology for removal of volatile organic compounds (VOCs), pyrolysis of non-VOCs, treatment of organic residues, and in situ vitrification of soils and asbestos. There have been bench-scale tests of the technology for remediation applications.

Moisture content of soil affects power requirements. The contaminants are not treated in a confined area, so some migration of the materials being treated is possible. This technology has not been field tested for remediation applications.

Technology Cost
No available information.

T0096

BioEnviroTech, Inc.

BioPetro

Abstract
BioPetro™ is a bacterial product formulated to provide facultative bacteria selected for in situ bioremediation of refined and crude hydrocarbons, such as fresh and weathered crude oils, heavy

heating oils, tars, heavy petrochemicals, and oil sludges, in soils and waters. The BioPetro cultures are a stable dry powder blend of naturally occurring bacteria which are preserved through use of air-drying techniques. The formulation includes powdered nutrients, wetting agents, and buffers.

BioEnviroTech, Inc., is a supplier of bacterial products based upon natural saprophytic (those that digest only dead organic matter) and facultative (those that can modify their metabolism to live in the presence of free oxygen and with exposure to sunlight) bacteria for bioremediation. The technology is commercially available and has been tested by the National Environmental Technology Applications Center (NETAC) of the University of Pittsburgh Applied Research Center.

A pH range of 5.5 to 8.5 and a temperature range of 45 to 110°F is required. The bacteria require at least 10 parts per million (ppm) nitrogen and 5 ppm phosphorus. The optimum bioremediation will occur between 3 and 5 mg/liter dissolved oxygen. Extreme salinity, strong acids, caustics, disinfectants, germicides, and chlorine may limit the activity or kill the bacteria.

Technology Cost

In 1997, researchers at Fort Hood Army Base calculated the average cost of bioremediation using BioPetro technology was less than $\$50/m^3$, which included the cost of microbes, nutrient, equipment, worker hours, and technical support. During the initial demonstration of the technology at the base, bioremediation of 230 m^3 of soil cost \$13,500, compared with an estimated \$45,000 for remediation at the site by burning the soil (D179388, p. 35). According to the vendor, for five projects at Fort Hood in Texas, the cost of bioremediation with BioPetro has averaged $\$45/yd^3$ cubic yard (D15748W).

Information Sources

D15748W, Vendor literature
D179388, Klinger, 1997

T0097

Biofilm Barrier — General

Abstract

Biofilm is being researched for potential use as an in situ barrier technology. It is not yet commercially available. Biofilm is an organic material consisting of microorganisms embedded in a self-made polymer matrix. It is formed when bacteria are introduced into soil and stimulated with specific nutrients.

Research is currently focusing on ways to lower the hydraulic conductivity of engineered biofilms to make them an effective barrier to contaminant transport; this includes the introduction of ultramicrobacteria (UMB) to penetrate the soil matrix.

Several approaches have been suggested for the future implementation of biofilm barrier technology. There are several potential applications of the technology, including liners for landfills or surface impoundments, covers for landfills, and in situ vertical cutoff walls.

Soils with high percentages of gravel or other large particle sizes would not be good candidates for biofilm treatment.

Technology Cost

No available information.

T0098

BioGEE International, Inc.

BioGEE HC

Abstract
BioGEE HC™ is a bioremediation product for the in situ or ex situ remediation of soil or groundwater. It consists of a blend of several strains of aerobic microorganisms selected for their ability to degrade hydrocarbon contaminants. The BioGEE HC technology has been used in multiple full-scale applications and is commercially available.

The blend of microorganisms in BioGEE HC are selected for their abilities to degrade hydrocarbon constituents, with the individual strains targeted at specific hydrocarbon degradation products. BioGEE HC are aerobic bacteria and require a dissolved oxygen level in water of at least 3.0 parts per million (D15672T, p. 20). Other limitations include pH levels greater than 12 and less than 5, the presence of substances toxic to microbes, lack of nutrients, soil temperature below 50°F, and insufficient moisture.

All information was provided by the vendor and could not be independently verified.

Technology Cost
The U.S. Environmental Protection Agency's VISITT 4.0 database (1995) estimates a price range of \$25.00 to \$40.00/yd^3 for in situ soil applications, however, no price information was supplied to RIMS by the vendor (D10066T, p. 13).

Information Source

D10066T, VISITT 4.0, 1995

T0099

BioGenesis Enterprises, Inc.

BioGenesis Soil and Sediment Washing Process

Abstract
The BioGenesis soil and sediment washing systems combine cleansing and enhanced biodegradation in a two-stage process to treat contaminated soil, sludge, and sediments. Ex situ methods involve using specialized, mobile equipment to apply the cleanser, agitate the soil, separate the contaminants, and initiate biodegradation. The technology can also be applied in situ by injecting the cleanser directly into contaminated soil or sediment.

According to BioGenesis, the soil and sediment washing technologies can treat inorganics such as heavy metals. The vendor also claims that these technologies can treat most organics, including volatile and nonvolatile hydrocarbons, chlorinated hydrocarbons, pesticides, halogenated solvents, fuel oils, chlorinated phenols, gasolines, jet fuel, polychlorinated biphenyls (PCBs), total petroleum hydrocarbons (TPH), dioxins, and polynuclear aromatic hydrocarbons (PAHs). The BioGenesis soil and sediment washing technologies are commercially available.

According to the vendor, soil washing offers the following potential advantages:

- Air emissions can be controlled during operation.
- Site-specific water treatment systems recycle wash water.

- Nonpolluted soils remain on site.
- Treated materials are limited to clean soil, treated water, and a recyclable or reclaimable pollutant.
- The technology takes advantage of natural processes.
- A wide range of contaminants can be treated.
- Soils with high clay content and heavily weathered contaminants can be treated.

High-metal concentrations may be toxic to the microorganisms involved in the biodegradation of organics. In addition, cold temperatures may adversely affect biodegradation rates. As with any ex situ process, BioGenesis soil and sediment washing requires considerable materials handling.

Technology Cost

According to the vendor, the cost for the BioGenesis soil and sediment washing technologies can range from \$40 to \$200 per ton. This range reflects variables such as contaminant type and amount, soil type, project size, and target cleanup levels. The average cleaning cost ranges from \$60 to \$130 per ton (D11063U, p. 3; D19855E, p. 2).

According to a U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) report, treatment costs for the BioGenesis soil washing technology are affected by the following factors:

- Type and concentration of contaminants
- Treatment goals
- Volume of contaminated soil
- Physical site conditions
- Geographical site location
- Site accessibility
- Availability of utilities (D10256X, p. 30)

The BioGenesis soil washing system also produces residual wastes that may require either additional treatment or off-site disposal. This factor can also affect treatment costs (D10256X, p. 30).

Based on data from a SITE demonstration in 1992, costs associated with the BioGenesis soil washing technology were attributed to the following categories: site preparation, permitting and regulatory requirements, capital equipment, labor, consumables and supplies, utilities, residual/waste shipping and handling, analytical services, and demobilization. The majority of costs were associated with site preparation, capital equipment, and residual/waste shipping and handling (D10256X, p. 30). In 1993, the EPA estimated that total treatment costs range from \$74/yd^3 (based on treating 2000 yd^3 of soil) to \$160/yd^3 (based on treating 500 yd^3 of soil) (D10256X, p. 29).

In 1993, a treatability study was conducted using the BioGenesis sediment washing technology at Thunder Bay in Ontario, Canada. Based on study results, full-scale treatment costs for the technology were estimated to be between \$40 and \$200 per ton. This estimate assumed the use of a batch-feed system to treat 10,000 tons of contaminated media. For a continuous-feed system, full-scale costs were estimated to range from \$30 to \$110 per ton of contaminated media. Capital costs were estimated to be between \$400,000 and \$800,000 depending on the type of system implemented (D205356, p. 4-4).

In 1999, a pilot demonstration began in Keary, New Jersey, to treat 10,000 yd^3 of dredged sediments. The budget for this demonstration was \$1,000,000. The full-scale operation was expected to begin in 2000. Water Resources Development Program managers estimated the cost of the full-scale system to be at or below \$35/yd^3 (D19861C, pp. 1, 2; D19859I, p. 7).

Sediments treated with the BioGenesis process can be mixed with humates, lime, and other organic materials to produce a manufactured topsoil. According to the U.S. EPA, the sale of this topsoil can off-set some of the costs associated with the technology (D22273B, p. 26).

Information Sources

D10256X, U.S. EPA Innovative Technology Evaluation Report, 1993
D11063U, BioGenesis Enterprises, Inc., vendor information
D18600P, Roy F. Weston, Inc., 1998
D19855E, vendor literature, undated
D19859I, U.S. EPA, 1998
D19861C, U.S. EPA, 1999
D205356, U.S. EPA, 1997
D22273B, U.S. EPA, 1999

T0100

BioGenesis Enterprises, Inc.

BioGenesis Soil Remediation and Cleaning Products

Abstract
BioGenesis has developed over 20 proprietary biodegradable products for soil remediation and industrial cleaning. The products are available in various strengths and formulations to clean soil or aqueous wastes contaminated with organics. The products are made from plant extracts that not only provide cleaning power but also accelerate the pollutant biodegradation by naturally occurring microorganisms. They are especially effective on oil and grease. Two of the products, BG-Clean™ 401 and 403, are authorized dispersants on the U.S. Environmental Protection Agency's (EPA's) National Contingency Plan (NCP) Product Schedule for oil spills in water. Products are available to treat chlorinated and petroleum hydrocarbons, pesticides, polychlorinated biphenyls (PCBs), and polyaromatic hydrocarbons (PAHs).

The BioGenesis soil remediation and cleaning products can be used for general-purpose and emulsion-degreasing applications in oil refining, utility, automotive, manufacturing, and transportation industries. They can be used in situ or in conjunction with mechanical cleanup systems.

BioGenesis claims that their chemical formulations display the following characteristics in applications across the spectrum of industrial and institutional cleaning:

- The proprietary chemical blends or cleaners effectively accelerate the biodegradation of most organic pollutants.
- In controlled environments, the cleaners can be used to reduce and/or clean waste generated by industry.

Technology Cost
No available information.

T0101

Bio-Genesis Technologies

Aerobic Biotreatment System (ABS)

Abstract
The Aerobic Biotreatment System (ABS) is an in situ technology that treats soils, sludge, and sediments contaminated with petroleum hydrocarbons, polyaromatic hydrocarbons (PAHs),

aromatics, alcohols, ketones, phenols, polychlorinated biphenyls (PCBs), solvents, carbohydrates, and pesticides. Soil can also be excavated and treated in a containment area. According to the vendor, the technology has been successfully demonstrated at bench-scale, pilot-scale, and full-scale levels and commercially available through the company.

The ABS will not degrade inorganic or synthetic compounds. The technology's efficiency varies with temperature, moisture, site geological, and chemical characteristics. A biotreatability study may be required to determine a treatment application.

Technology Cost

No available information

T0102

Bio-Genesis Technologies

Bioremediation — GT-1000

Abstract

Bio-Genesis Technologies's bioremediation technology is an ex situ treatment that utilizes bioaugmentation to remediate soil, water, and sludges. A synergistic group of microorganisms, named GT-1000, are used to digest hydrocarbons, oil and grease, coal tars, phenolic compounds, and chlorinated organic solvents. The microbes are nonpathogenic and use the petroleum products as a carbon and energy source. According to the vendor, the GT-1000 technology has been successfully demonstrated at bench-scale, pilot-scale, and full-scale levels.

The GT-1000 microbes cannot degrade inorganic compounds and the biodegradation rates are dependent on temperature, moisture, and slurry and chemical characteristics.

Technology Cost

Bio-Genesis Technologies's GT-1000 bioaugmentation technology was employed by a repair garage located in Massachusetts to treat sewage from a 200-gal separator. The garage is required to maintain total petroleum hydrocarbon levels under 100 mg/liter. The previous remediation method of pump and disposal averaged $16,000 per year. According to the vendor, the yearly cost of using the GT technology, including nightly microbial injections and monthly nutrient additions, was $1200 (D15330A, p.17).

Information Source

D15330A, Bio-Genesis Technology, Inc.

T0103

Biogenie SRDC, Inc.

Treatment Process for Mercury-Contaminated Soil

Abstract

Biogenie SRDC, Inc. (Biogenie), has developed a pilot-scale ex situ system for the treatment of soil contaminated with elemental, metallic mercury. The basis of the process is the transformation of the soil into a sludge, called pulp, allowing for the release of the mercury. Mercury droplets are then recovered and concentrated, and the treated soil is dehydrated. The technology is commercially available.

The vendor claims that the technology can be used to remove all visible mercury from soil. They claim that the technology can be adapted to different soils, and can be used in combination with other treatments such as biodegradation and chemical extraction to allow for additional volume reduction of soil requiring disposal.

The process only recovers metallic, elemental mercury. All information is from the vendor and has not been independently verified.

Technology Cost

In 1992, the estimated treatment cost associated with the technology was \$211/m^3 of soil treated. This assumes the treatment of 25,000 m^3 of soil at a treatment rate of 2.5 m^3/hr. This costs includes engineering and development costs, equipment and installation costs, and all other costs related to process operation and burying of the treated soil (D16706Q, p. ix).

Information Source

D16706Q, PPG Canada, Inc. 1992

T0104

Biogenie, Inc.

Biogenie Biofiltration Process

Abstract

This is a biological air treatment technology that uses an air/water separator, trickling filter, and biofilter for removal of organic contaminants and to reduce odor. The technology is currently commercially available in Canada but is not available in the United States. The company has expressed interest in expanding operations to France.

Waste gas is first drawn in through the air/water separator, used to remove impurities in the air such as water droplets, solid particles, etc. The effluent then travels to the trickling filter, which is a packed column of very porous polymer material. The use of a polymer as the packing material enhances mass transfers between the liquid and gas. The polymer can fix a large culture of specific bacteria capable of degrading contaminants found in the liquid phase. The trickling filter is followed by a compost-based biofilter that removes residual contaminants.

The technology does not handle metals.

Technology Cost

No available information.

T0105

Biogenie, Inc.

Biogenie Biopile

Abstract

The Biogenie Biopile process is an ex situ bioremediation technology for organics-contaminated soils. The Biogenie Biopile process is a patented technology. The technology has been demonstrated in full-scale operations; over 500,000 tons of contaminated soil has been treated using this process. The technology is currently commercially available in Canada, but is not available in the United States. The company has expressed interest in expansion to France.

The Biogenie Biopile system has a pad on which contaminated soils are stockpiled. Soil moisture and nutrients are monitored, and a pump draws air from or pushes air into the pile to oxygenate it. An underdrain connected to a reservoir collects leachate and an impermeable sheeting that covers the soil pile for air and water control. Off-gases from biopile operations are subsequently treated by a gas cleaning system such as the Biogenie Biofilter.

The technology cannot remove metals or other nonbiodegradable compounds. Also, the technology may have difficulty attaining decontamination criteria in highly contaminated soils. In some cases, treatment periods can last between 18 and 40 weeks.

Technology Cost
Costs for the Biogenie Biopile technology, as of 1995, were estimated at $90.00/m^3$. This price includes all operations, from initial excavation to their return following treatment (D13746M, p. 3).

Information Source

D13746M, DESRT Project Summary, 1995

T0106

Biological Activated Carbon — General

Abstract
Biological activated carbon (BAC), a commercially available ex situ technology designed for groundwater remediation, is capable of treating contaminants such as benzene, toluene, and xylenes. This technology integrates biological degradation and granular activated carbon (GAC) adsorption into a single unit process. The growth of microorganisms on the surface of the GAC particles and the resulting biodegradation of the adsorbed waste constituents increases the removal capacity of GAC.

TABLE 1 Leachate Treatment Costs

Design Flow[a]	Chemical Oxygen Demand (COD)		Metals Removal Unit	Sludge Dewatering	System Mode	Capital ($million)	O&M ($1000 lb COD)	O&M ($1000 gallon)
0.035[b]	Influent	843	No	Yes	Batch	0.37	28	4.3
	Effluent	600						
0.040[c]	Influent	1,812	Yes	Yes	Continuous	—	1.7–2.0	25–30
	Effluent	75						
0.033[d]	Influent	1,150	No	No	Batch	0.27	0.13	1.2
	Effluent	400						

Source: Adapted from D170058.
[a]Design flow: million gallons per day.
[b]The capital cost included the complete powdered activated carbon system (tankage, blowers, pumps, instruments/controls, etc.), carbon feed system, sludge storage tank, filter press, O&M manuals, startup and training services, no building. The O&M cost covers the leachate treatment and solids dewatering.
[c]No capital cost information was available. All tanks are covered.
[d]The capital cost included two batch powdered activated carbon systems, two carbon feed systems, O&M manuals, startup and training services. The O&M costs pertain only to the leachate treatment plant.

TABLE 2 Groundwater Treatment Costs

Design Flow[a]	Chemical Demand	Oxygen (COD)	Metals Removal Unit	Sludge Dewatering	Carbon Regeneration	Capital ($million)	O&M ($/lb COD)	O&M ($1000 gallon)
1.8[b]	Influent	6,000	No	Yes	Yes	—	0.04–0.6	2–3
	Effluent	<100						
0.0245[c]	Influent	130	No	No	No	0.15	1.6–2.0	1.7–2.2
	Effluent	<50						
0.003[d]	Influent	11,500	Yes	Yes	Yes	0.18	1.0	100
	Effluent	66						

Source: Adapted from D170058.
[a] Design flow: million gallons per day.
[b] Maintenance and operation of single-stage continuous powdered activated carbon system, 10 gal/min wet-oxidation unit, solid disposal, groundwater pumping, neutralization, and effluent discharge.
[c] The capital cost includes a batch powdered activated carbon system, groundwater equalization tank, O&M manual, startup and training services, and 6 months of site operational services. O&M costs cover the entire contaminated groundwater cleanup operation, including analytical.
[d] The capital cost includes covered tank, carbon feed system. O&M costs cited are for groundwater treatment, air emissions control/treatment, sludge dewatering/disposal, and analytical.

Metals removal may require pretreatment. Other applications may require equalization tank, oil/water separator, sludge dewatering, postcarbon adsorption or filter. Certain applications may require off-gas control system. It may also be unsuitable for groundwater with a chemical oxygen demand less than 40 mg/liter.

Technology Cost

Capital and operations and maintenance (O&M) costs are different for leachate or groundwater treatment and depend on design flow of the system and level of treatment. Table 1 gives sample costs for leachate treatment, and Table 2 gives sample costs for groundwater.

Information Source

D170058, EPA Manual, GroundWater and Leachate Treatment Systems, 1995

T0107

Biomet Mining Solutions Corporation

Biosulfide Process

Abstract

The biosulfide process is an ex situ, chemical and biological process used to treat groundwater, wastewater, and acid mine drainage contaminated with dissolved metals and high levels of sulfate ions. In the biological reactor, naturally occurring, anaerobic, sulfate-reducing bacteria, such as *Desulphovibrio desulphuricans*, are used to convert sulfate ions to sulfide ions and generate alkalinity. The sulfide ions are stripped into the gas phase as hydrogen sulfide and transferred to the chemical reactor. The alkalinity from the bioreactor neutralizes the acidity of the water in the chemical step. In the chemical reactor, the sulfide combines with dissolved metals to precipitate sulfides. The metal sulfides are then recovered from the process.

The biosulfide process is a commercially available, patent-pending technology. The first pilot-scale plant was constructed at the former Britannia Mine near Vancouver. A full-scale biosulfide plant has been constructed at a zinc refinery in the Netherlands. According to the Canadian Biotechnology Strategy Taskforce, the biosulfide process needs to improve its selective precipitation of metals and its ability to treat highly contaminated effluents and larger flow rates.

Technology Cost

Operating costs for the biosulfide process are determined by the costs of the carbon and energy source added to the bioreactors, the added nutrients, labor, and power. According to the vendor, the operating costs for pilot-scale, laboratory testing were $0.80/m^3 of treated acid mine drainage (D16057G, pp. 503, 504).

Based on the pilot-scale operation at the Britannia Mine, the vendor estimated the full-scale capital costs to be $2.5 million. Zinc and copper sulfates in the processed waste may be sold to smelters. The sale of these metals was estimated to produce a potential net operating profit for the plant of $130,000 per year (D16056F, p. 38).

Information Sources

D16056F, Rowley et al., 1997

D16057G, Warkentin et al., 1994

T0108

Biomin, Inc.

Organoclay

Abstract

Organoclay is an ex situ, commercially available treatment for the removal of hydrocarbon liquids such as oil, grease, diesel, and jet fuel from water and for the stabilization of organic hazardous wastes. Organoclay can be used as a pre- or postpolishing step in numerous applications to absorb up to 60% of its weight in oil, grease, or other large hydrocarbons; granular activated carbon (GAC), on the other hand, typically absorbs only 10 to 20% of its weight.

Organoclay is made of a montmorillonite clay such as bentonite, which is modified with a quaternary amine, and then either granulated and blended with anthracite for use in filtration vessels, or powdered for use in liquid batch applications. Organoclay/anthracite is used as a polishing step in situations where the feed stream is variable and traditional treatments are not as effective. The blend removes substantial quantities of organics and heavy metals, although organoclay alone cannot remove organically bound lead.

Organoclay outperforms GAC in high-temperature situations and has been found to be effective in refineries where temperatures reach 185°F.

According to the vendor, organoclay has several advantages:

- Lengthens the life span of GAC polishing systems.
- Reduces treatment costs.
- Removes oil and grease from water faster than GAC alone.
- Treats a variety of contaminants.

Once organoclay has absorbed to its capacity, it is not easily cleaned. Spent media must be landfilled or incinerated.

Technology Cost

In 1998, the vendor stated that organoclay treatment costs range from 3 to 6 cents per gallon of treated water (D17268T, p. 19).

According to the vendor, the approximate cost of using organoclay to remove oil and grease from wastewater at the U.S. Department of Defense's (DOD's) Hill Air Force Base in Utah was \$0.55 to \$0.65 per 1000 gal. The influent water contained grease, chlorinated hydrocarbons, and heavy metals. It is not clear whether this cost estimate was for the entire treatment system or only for oil and grease removal (D14900I).

At a pharmaceutical manufacturing facility in New York, an organoclay–carbon filtration system was installed to treat wastewater contaminated with emulsified white petroleum, stearic acid, fatty acid stearates, fatty alcohols, mineral oils, and oxyethylene ethers and stearates. The system consisted of 159 kg of organoclay and 86 kg of activated carbon. The entire system cost \$8000 (D17267S, p. 29).

The wastewater at an aircraft-component manufacturing plant contained free and emulsified oil. The water was treated using 454 kg of organoclay followed by a reverse-osmosis system. The organoclay portion of the treatment train cost \$5000. The organoclay was replaced once a year. Replacement and disposal costs was approximately \$3000 (D17267S, p. 30).

At a former manufactured gas plant, 3 million gallons of wastewater contaminated with polycyclic aromatic hydrocarbons (PAHs); oil; benzene, toluene, ethylbenzene, and xylenes (BTEX); and heavy metals were treated using an organoclay treatment train. The system consisted of an oil/water separator; bag filters; 9000 lb of organoclay; and 6000 lb of GAC. Treatment costs were approximately \$0.12/gal of treated water (D21556F, p. 12; D17268T, p. 29).

In 1996, an oil/water separator and 1200 lb of organoclay were used to treat wastewater at an oil field in central Michigan. The system's installation costs were approximately \$5900. The quarterly replacement costs for the organoclay were \$1500. The organoclay's disposal costs were \$40 every 3 months (D21556F, p. 45).

The vendor states that due to the cost of spent carbon replacement, the cost savings for prefiltering wastewater through one tank of organoclay prior to activated carbon filtration is approximately \$7115 per year, but probably depends on throughput (D14900I).

In a case history from a fabrication facility in Kentucky, organoclay was used in conjunction with a filter bag to reduce oil and grease levels in wastewater from 30 to 50 parts per million (ppm) to less than 5 ppm. Following the filtration, the water passed through one drum of organoclay at a flow rate of 0.25 gal/min. The clay is changed twice annually and operating costs are said to be less than \$5000 per year (D17154K, p. 60).

Information Sources

D14900I, Biomin, Inc., date unknown

D17152I, Pollution Engineering Casebook, 1997

D17154K, Alther, June 1997

D17267S, Alther, 1998

D17268T, Alther, 1998

D21556F, Biomin, Inc., 2000

T0109

Bio-Reaction Industries, Inc.

BRI-170/270

Abstract

The BRI system is a biofiltration technology designed to treat volatile organic compounds (VOCs). The vendor claims this technology is effective for solvent-laden airstreams originating

from depressurizing aerosol cans containing VOC as propellant, drying-solvent-laden rags, drying liquid still bottoms, and drying paint sludge. According to the vendor, BRI systems have been placed in fiberglass manufacturers, paint facilities, and household hazardous waste and treatment facilities.

The vendor claims the following benefits for the technology:

- Reduces facility discharge of VOCs that can be measured and documented.
- Allows recovery of solvent-laden rags, sludges, or recycling of still bottoms for reuse.
- Self-regulating; eliminated the need for charcoal filter changes and disposal.
- Entire process is done on site.
- Simple to operate and monitor.

The BRI system was developed and patented (5,518,920) by Bio-Reaction Industries, Inc. It is currently commercially available for treatment of VOCs.

All information is from the vendor and has not been independently verified.

Technology Cost
According to the vendor, the cost of electricity to run either BRI system is $1.80 per day based on $0.08/kWh (D16816V, p. 2).

Information Source

D16816V, Bio-Reaction, Inc., date unknown

T0110

Biorem Technologies, Inc.

Soil Pile Bioremediation

Abstract
Biorem Technologies, Inc., has developed several ex situ commercially available bioremediation systems. The company offers an ex situ soil pile bioremediation technology for volatile organic compounds (VOCs). The soil pile relies on bacteria to break down the target contaminants. In some cases the indigenous bacteria are stimulated with nutrients or amended with other cultures of bacteria. Perforated piping is placed in the pile and connected to a vacuum to draw ambient air from the pile, thereby removing the volatile contaminants. The air is then run through a biofilter where the contaminants are adsorbed and biodegraded.

The company has applied ex situ landfarming technology to several sites. The process is designed to contaminated site containing polycyclic aromatic hydrocarbons (PAHs), phthalate esters, petroleum hydrocarbons, and pentachlorophenol (PCP). The company has also used in situ techniques such as air sparging bioremediation.

These technologies are not appropriate for sites contaminated with metals.

Technology Cost
No available information.

T0111

BioRemedial Technologies, Inc.

Compound C

Abstract
Compound C is an additive designed to enhance the aerobic biodegradation of trichloroethylene (TCE). Compound C is a cometabolite, which allows TCE to be indirectly degraded in situ by

microorganisms in an aerobic environment. This technology may be applied to contaminated soil or groundwater.

The vendor also incorporates other technologies to act in conjunction with biodegradation, such as air sparging, soil vapor extraction, or pump-and-treat systems. This technology is patented and is commercially available from BioRemedial Technologies, Inc. All information contained herein was provided by the vendor and has not been independently verified.

As with any bioremediation technology, high or low pH may inhibit microbial activity. Extreme temperatures also inhibit microbial activity, and high concentrations of contaminants may be toxic to microorganisms.

Technology Cost
There is no available information regarding the costs associated with this technology.

T0112

Bioremediation of Explosives: Contaminated Soil — General

Abstract
Microbe strains can be used to bioremediate soils contaminated with explosives such as 2,4,6-trinitrotoluene (TNT), cyclo-1,3,5-trimethylene-2,4,6-trinitramine (RDX), high melting explosives (HMX), dinitrotoluene (DNT), tetryl, and nitrocellulose. This technology optimizes the microbial environment in the soil to affect gradual metabolization of contaminants by naturally occurring microbes. Several methods are available for the treatment of explosives-contaminated soil including aqueous-phase bioreactor treatment, composting, landfarming, and white-rot fungus treatment.

Benefits of this technology include the following:

- Concentrations of explosives can be degraded to levels well below required cleanup goals.
- Intermediate products are also degraded.
- Operation permits for bioremediation can be issued rapidly, thus avoiding problems common to incinerator projects.
- Uses little nonrenewable fossil fuels.

This technology is commercially available from several vendors.

Each site and material must be evaluated before implementing a biological solution. The soil is examined in chemical laboratories to assess the type and extent of the contamination. The microbiological laboratory analyzes the presence and activity of the local microbial strains in the contaminated soil. Biologists then specify the type and quantity of natural additives required to produce maximum degradation rates.

Technology Cost
One source estimated the cost of bioremediating explosives-contaminated soil to be \$50 to \$400 (1995 dollars) per cubic yard of soil treated. This estimate does not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals. A U.S. Army study estimated that to treat less than 10,000 tons of contaminated soil, the cost would be \$651 per ton for mechanically agitated composting, and \$386 per ton for windrow composting (D17224H, p. 29).

Factors that have a significant effect on unit price include the following:

- Initial contaminant concentration
- Quantity of waste
- Target contaminant concentration

- Characteristics of soil
- Waste handling/preprocessing
- Depth of contamination
- Site preparation
- Amount of debris with waste (D10069W, p. 23)

Information Sources

D10069W, VISITT Version 4.0, 1995
D17224H, U.S. EPA, 1993

T0113

Bioremediation Service, Inc.

Aquaplant Biofilter System

Abstract
Aquaplant® is a commercially available, ex situ biological treatment system that purifies wastewater by using artificial wetlands to filter out and biodegrade contaminants. Wastewater flows through two or more Aquaplant basins constructed at slightly different elevations. Each basin contains water, soil, and plants appropriate for the site and the contaminants being treated. Wastewater flows either continuously via gravity, or discontinuously via pump, through the plant growth filter of the first basin and then through a second (or subsequent) similar basin. Once wastewater has been filtered through the last basin, clean effluent is recycled or discharged into a receiving stream.

The vendor claims Aquaplant can reduce chemical oxygen demand (COD), biological oxygen demand (BOD) of wastewater, and is able to treat effluent containing volatile organic compounds (VOCs), ammonium, nitrates, trinitrotoluene (TNT), hydrocarbons, mineral oils, and heavy metals. Suitable Aquaplant applications include private and municipal household wastewater; surface, cooling, and industrial process water; landfill leachate and the remediation of artesian and drainage water. According to the vendor, Aquaplant is also suitable for the remediation of storm water runoff and for temporary or long-term expansion of existing purification facilities. The vendor states Aquaplant has been used to remediate wastewater from steel factories, petroleum tank farms, oil collector tank contents from ships, and pretreated seepage water from dump grounds.

An advantage of Aquaplant is that it can be an effective remediation alternative that requires minimal investment due to low operating costs. Also, Aquaplant is typically and more acceptable than an industrial water treatment facility.

Aquaplant is not suitable for the remediation of aromatic hydrocarbons benzene, toluene, ethylene, and xylene (BTEX), polychlorinated biphenyls, volatile chlorinated hydrocarbons, pesticides, dioxins, and furans.

During colder weather, contaminant degradation rates decline since the activity of the substrate microorganisms decreases. If frost develops, pumps and tubes have to be isolated. In colder weather, clean effluent depends mainly on the plants' ability to adsorb pollutants. During warmer weather, the activity of the microorganisms increases and contaminant degradation rates improve.

Technology Cost
According to the vendor, capital costs for the Aquaplant system are approximately \$200 to \$300/yd^2 of surface area. This estimate is based on the following assumptions:

1. Possible pollutants include COD, BOD, nitrogen compounds, and hydrocarbons.
2. Capacity is 125 to 2500 gal of wastewater per hour, retention time of 1 to 10 days.
3. Supplementary process includes pretreatment (D120854).

Information Source

D120854, Bioremediation Service, Inc., date unknown

T0114

Bioremediation Technology Services, Inc.

BTS Method

Abstract
The Bioremediation Technology Services (BTS) technology is a bioremediation technology for organic contaminants. This technology has been used in multiple full-scale applications and is commercially available. The process is patented and has been under scientific investigation since the 1970s.

BTS, Inc., begins by preparing a consortia of microorganisms that are adapted to survive in a humic polymer environment (common humus) and that are compatible with each other. Among these groups are individual microorganisms capable of degrading (mineralizing) aliphatic and aromatic hydrocarbons, both chlorinated and not. By manipulating the contents of the humic environment, BTS is able to increase the population of the introduced microbes to enormous numbers. After introducing these microflora to a contaminated soil, it is only a matter of time until the unwanted substance(s) is mineralized.

The petroleum hydrocarbon contaminant is brought into direct contact with the specific microorganisms contained in BTS. These microscopic bacteria ingest the hydrocarbon molecules. For this entire process to begin, the contaminated soil and BTS product must be brought into direct contact.

Technology Cost
Two examples of BTS costs follow:

- Delhi, Louisiana, 1993. Fifty cubic meters of soil at a pesticide distributor's site contaminated with toxaphene were treated. Toxaphene concentrations were reduced from 16,000 to 40 parts per million (ppm). Cost was $\$25/yd^3$.
- Santa Clara, California, 1992. Twelve thousand cubic meters of soil at a public transit company facility were contaminated with diesel fuel. Concentrations were reduced from 15,000 to 80 ppm, at a cost of $\$15/yd^3$.

The vendor did not specify what was and was not included in these costs.

Information Source

D10044N, VISITT 4.0

T0115

Bioscience, Inc.

BIOX Biotreater

Abstract
The BIOX™ biotreater is a commercially available, ex situ technology for the treatment of wastewater, groundwater, and surface water containing organic contaminants. The BIOX biotreater is a biological submerged, fixed-film reactor capable of aerobic, anoxic, or anaerobic operation.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0116

Bioscience, Inc.

Microcat

Abstract
Microcat® (meaning microbial catalysts) products constitute a bioremediation technology used on wastewaters, sludges, and soils. Microcat products include specialized microbial cultures, nutrients, and surfactants to remediate organic contaminants such as petroleum hydrocarbons. The products used in site remediation include:

- Microcat-NPC. Nitrogen and phosphorus salts in time release form
- Microcat-NPN. Nitrogen and phosphorus salts to augment site nutrients
- Microcat-XBS. Specialized microbes for degradation of hydrocarbon contaminants
- Microcat-PH. Water-soluble salts for control of pH
- Microcat-P. Phosphorus salts to augment site nutrients
- Microcat-SH/SL. Biodegradable wetting agents (surfactants)

These products are commercially available and have been used in multiple remediations.
All information has been provided by the vendor and has not been independently verified.

Technology Cost
According to the vendor, Microcat products generally cost less than one cent per pound of soil treated (D14399R, p. 2).

Information Source

D14399R, vendor literature

T0117

Bioslurping — General

Abstract
Bioslurping is a commercially available, in situ technology that combines vacuum-enhanced free-product recovery with bioventing of subsurface soils to simultaneously remediate petroleum-hydrocarbon-contaminated groundwater and soils. Vacuum-enhanced recovery utilizes negative pressure to create a partial vacuum that extracts free product and water from the subsurface. Bioventing is forced aeration to accelerate in situ bioremediation of hydrocarbons and non-aqueous-phase liquids (NAPLs).

The technology, available from a number of vendors, is portable and uses a single pump to extract free product, groundwater, and soil gas from multiple wells. Groundwater and soil gas may require treatment before being discharged. Bioslurping is used at petroleum spill sites and has proven most effective in fine-to-medium textured soils or fractured rock in areas with a low water table.

Pilot studies and field applications have shown vacuum-enhanced pumping to increase the rate of free-product recovery and in many cases significantly reduce the amount of groundwater recovered with the free product.

Technology Cost

The cost of remediating the soil and groundwater at a site containing a gasoline and diesel plume approximately 80 by 35 m and containing 15,000 to 25,000 liters of product was estimated to be $80,000 for system design and installation and $40,000 per year for operating expenses in 1994 (D12052V).

At another site, the cost of remediation of gasoline- and fuel-oil-contaminated soil was estimated to be $100 to $120 per ton; however, if the unit was used at more than one site, net treatment costs could be as low as $20 to $30 per ton (D12140U, p. 34).

ENSR Consulting and Engineering, a vendor of bioslurping technology, provided the following cost estimate of the technology. For the purposes of the estimate, a 2-acre site requiring 50 wells is assumed. Treatment time is estimated to be 3 years. For such a site, an installation and trial run is estimated to cost $300,000. Operation for 3 years is estimated to cost $50,000 per year, for a total estimated cost of $450,000 (D18685A, p. 2).

Information Sources

D12052V, Connolly et al., 1995.

D12140U, September/October, 1995

D18685A, Baker, undated web page

T0118

Biosorption — General

Abstract

Biosorption is the sorptive removal of toxic metals from solution by specially prepared biomass. This technology is being developed for the in situ or ex situ treatment of soils or water contaminated with heavy metals and radionuclides. Many microorganisms, including certain strains of bacteria, yeasts, filamentous fungi, algae, and plant cells, have the capacity to accumulate metallic cations from the environment via biosorption. Because the biological treatment occurs at ambient temperature and pressure in the absence of harsh or corrosive reagents, it is inexpensive and yields no noxious secondary wastes.

The binding capacity of biomass may be significantly decreased by low pH (below 3.5) and by other complex factors including competition between cation species, metal sequestration with organic molecules in solution, and the physical form of the biosorbent matrix.

Technology Cost

No available information.

T0119

Biosurfactants — General

Abstract

Biosurfactants are commercially available compounds for the in situ or ex situ treatment of hydrocarbons and non-aqueous-phase liquids (NAPLs) in soil and groundwater. Surfactants are highly surface-active compounds that solubilize and/or mobilize contaminants in the subsurface.

Biosurfactants are natural, biodegradable surfactants synthesized by certain strains of bacteria, yeasts, and fungi.

Because biosurfactants are natural, biodegradable products, they are an attractive alternative to synthetic surfactants, particularly for in situ remediation. Biosurfactants are also potentially useful agents for oil spill remediation, where they can be used to disperse pollutants that remain in the water or have washed up on land.

Each surfactant molecule includes a hydrophobic, nonpolar portion, and a hydrophilic, polar portion. The polar portion is either nonionic (neutral), anionic (negatively charged), or cationic (positively charged). For more information on surfactants *see* T0759, Surfactants—General.

Technology Cost
No available information.

T0120

BioSystems Technology, Inc.

Biosolids-Enhanced Remediation (BER)

Abstract
Biosolids-enhanced remediation (BER) is an ex situ bioremediation technology used to treat soils contaminated with petroleum hydrocarbons and polycyclic aromatic hydrocarbons. The BER technology was developed by isolating particular microorganisms with the ability to degrade the specific components of petroleum products. The technology has been applied full scale and is commercially available.

The selected BER bacteria have been preacclimated to specific chemical constituents that make up products such as diesel and gasoline until these fuels become their preferred diet under favorable conditions. Therefore the individual constituents of petroleum products such as benzene, toluene, naphthalene, and dodecane are consumed by individual bacterial strains.

According to the vendor, advantages of the technology include:

- Lower costs relative to other bioremediation processes as a result of advanced technology
- Less time to reduce the level of contamination to an acceptable concentration
- Greater effectiveness in reducing or consuming the contaminant

High moisture content in the soil leads to packing, a reduction of void space, and decreased degradation rates.

Technology Cost
At a site in Chesapeake, Virginia, BER was used to remediate 5758 yd^3 of soil contaminated with petroleum hydrocarbons. Original cost estimates of \$500,000 were based on off-site incineration of the soil; however, the vendor states that remediation using the BER process saved over \$200,000 (D151406, p. 2).

Information Sources

D151406, Harris, undated

T0121

BioSystems Technology, Inc.

CSR (Chlorinated Solvents Remediation)

Abstract
BioSystems Technology's CSR process is an anaerobic bioremediation technology for soils and aqueous media contaminated with chlorinated compounds such as polychlorinated biphenyls

(PCBs). The CSR process is patented and proprietary, and at the field demonstration stage. It is expected to be commercially available in 1997.

The CSR system combines microbial dehalogenation processes with BioSystems Technology's aggressive BER process. The technology takes advantage of enzymes within certain, select bacteria that dechlorinate the target contaminants. According to the vendor, the technology assures that massive quantities of the bacteria are present and operating under the proper environmental conditions, thus assuring production of specialized enzymes.

CSR technology only works under anaerobic conditions.

Technology Cost
The vendor refers to the CSR process as cost effective and claims that it can save a significant amount of money; however, as no full-scale remediations have yet been conducted, no cost information is available (D151359, pp. 1, 2).

Information Source

D151359, vendor literature

T0122

Biotrickling Filter — General

Abstract
The biotrickling filter is a commercially available, ex situ technology for the treatment of airstreams contaminated with volatile organic compounds (VOCs), including chlorinated compounds. Biotrickling filters use microorganisms in a bed of supportive media to degrade organic compounds. A liquid solution is circulated, or "trickled," through the bed to enhance biodegradation.

Technology Cost
No available information.

T0123

BioTrol, Inc.

Biological Aqueous Treatment System

Abstract
The BioTrol biological aqueous treatment system (BATS) is a patented ex situ technology for treating groundwater and process water contaminated with organic compounds. The BATS technology has been successfully used to treat groundwater contaminated with pentachlorophenol (PCP), polynuclear aromatic hydrocarbons (PAHs), and gasoline and process water with high concentrations of substituted phenols.

The design of the BATS provides a high biomass concentration and mean cell residence time (MCRT) in a relatively small reactor volume, resulting in lowered production of sloughed biomass. The system's fixed-film reactor eliminates the added process of biomass separation by reducing sludge production. The BATS process does not seem to be hindered by the presence of suspended solids, metals, oil (free product), or other sources of organic carbon. A pilot-scale study using the BATS to successfully treat PCP-contaminated groundwater was conducted under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program in 1989.

TABLE 1 Vendor-Estimated Operating Cost of BioTrol Biological Aqueous Treatment System per 1000 Gal (3785 liters)

Item	At 5 gal/min (19 liters/min)	At 30 gal/min (114 liters/min)
Nutrients	\$0.042	\$0.017
Electricity	\$0.216	\$0.216
Heat[a]	\$1.46	\$1.46
Labor	\$1.49	\$0.50
Caustic	\$0.24	\$0.24
Total operating cost: \$/1000 gal (3785 liters)	\$3.45	\$2.43
Capital equipment		
Leased (mobile)	\$4,500/ month	N/A
Amortized (skid-mounted)	\$30,000	\$80,000

Source: From D12769P, p. 231.
[a]Not always required.

According to information from the vendor, Biotrol is currently not open for business and the BATS technology is no longer available.

Technology Cost

Table 1 details the vendor-estimated cost of operations at the BATS pilot plant in New Brighton, Minnesota, as well as at a large-scale [30 gal/min (57 liters/min)] system. Capital equipment is either a one-time or monthly charge, depending on whether a leased, mobile unit or an amortized, skid-mounted unit is used (see Table 1). The cost of site-specific pre- or posttreatment such as oil/water separators, filters, etc. must also be considered (D12769P, pp. 231–232).

Total capital and operating costs for the BATS system can be as low as \$2.94 per 1000 gal (\$0.78 per 1000 liters) of treated wastewater (D12307Z, p. 221).

Information Sources

D12307Z, Simon & McCulloch, Remediation/Spring 1992

D12769P, Stinson et al., February 1991

T0124

BioTrol, Inc.

Soil Washing Technology

Abstract

The BioTrol soil washing system is a patented, water-based volume reduction process used to treat excavated soil. It separates slightly contaminated, coarse, washed soil particles from heavily contaminated fine soil particles. The process operates on the premise that: (1) contaminants tend to be concentrated in the fine size fraction of soil (silt, clay, and soil organic matter); and (2) contaminants associated with the coarse soil fraction (sand and gravel) are primarily surficial. The BioTrol soil washing system can be used to treat soils contaminated with petroleum hydrocarbons, pesticides, polychlorinated biphenyls (PCBs), various industrial chemicals, and metals.

The process is economically attractive only when fines do not make up a high fraction of the soil and where the washed coarse soil fraction meets cleanup requirements and can be returned

to the site without further treatment. At one site, a problem with the metal contaminants having approximately the same grain size distribution as the sand being treated was addressed by the addition of another treatment step, a gravity separation step.

The BioTrol soil washing system makes use of an intensive scrubbing technology, unlike other approaches that are based almost entirely upon simple leaching. In addition, BioTrol utilizes a process development approach for each site. Pre-engineered modules are arranged in the optimal configuration for the unique soil and contaminant conditions. BioTrol's biological treatment technologies can be coupled, where applicable, with the soil washing system for treatment of the residual products (process water, contaminated fines, and debris), minimizing overall remediation costs.

According to information received from BioTrol in September 1999, the company is closed and the technology is no longer available.

Technology Cost

Soil washing unit costs are significantly lower for systems with larger throughput capacities or for fixed central facilities. In these cases, total soil washing costs could be in the range of $25 to $50 per ton (D10460Z, p. 38).

BioTrol soil washing system costs for the MacGillis and Gibbs Superfund site in New Brighton, Minnesota, were examined on both an integrated and a unit process basis. Costs for the demonstration study were extrapolated to full-scale treatment of the wood preserving site. The extrapolation included both operating costs and capital costs amortized over an assumed 10-year equipment life span. Costs were estimated in 1991 dollars.

If all three technologies [soil washing (SW), slurry bioreactor (SBR), and BioTrol aqueous treatment system (BATS)] are used, the estimated cost of a commercial-scale soil washing system is $168/ton ($185/metric ton). Incineration of woody material removed during washing accounts for 76% of the cost (D110690, p. 43).

On an individual unit basis, costs for the process were:

- SW: $170/metric ton ($154/ton) or $257/m^3 ($197/yd^3) of soil (with incineration of woody material)
- SBR: $9.22/1000 liters ($34.39/1000 gal) of 20% slurry
- BATS: $0.44/1000 liters ($1.65/1000 gal) of water treated

Without incineration, SW costs would drop to $29/metric ton ($27/ton) or $44/m^3 ($34/yd^3). The cost figures were developed as order of magnitude estimates (+50 to 30%). Costs for permitting and regulatory expenses were not included and effluent treatment and disposal for BATS and SBR were assumed not to be required (D10460Z, pp. 19, 22).

Information Sources

D10460Z, U.S. EPA, February 1992

D110690, U.S. EPA, 1994

T0125

BioTrol, Inc.

Methanotrophic Bioreactor System

Abstract

The Biotrol methanotrophic bioreactor system is an ex situ remedial technology that uses methanotrophic bacteria to degrade contaminants in groundwater. Methanotrophs use methane

as their sole source of energy and growth and are known for their ability to rapidly degrade halogenated hydrocarbons. The methanotroph used in the Biotrol system, *Methylosinus trichosporium OB3b* (OB3b), produces the soluble enzyme methane monooxygenase, which is primarily responsible for the degradation of contaminants within the Biotrol system.

The Biotrol system is comprised of two parts: (1) a suspended-growth culture vessel and (2) a bioreactor that is fed with contaminated groundwater and effluent from the culture vessel. From the culture vessel, the bacteria are transferred to the bioreactor and contacted with contaminated water. The bacteria degrade contaminants within the bioreactor.

In July 1990, the Biotrol system was demonstrated at the bench- and pilot-scale level under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) emerging technology program. During the demonstrations, a drop in OB3b methane monooxygenase activity revealed that the OB3b culture was unstable. During the demonstration, the extent of degradation of the contaminant trichloroethylene was highly variable.

The results of the EPA SITE demonstration also showed that the cost of methane necessary to support trichloroethylene biodegradation is not excessive in relation to the costs of other technologies available for the removal of trichloroethylene from water. Thus, the Biotrol system may prove to be a cost-effective alternative to more traditional groundwater remediation technologies.

According to information from the vendor, Biotrol is not opened for business and the methanotrophic bioreactor system is no longer available.

Technology Cost

In July of 1990, the Biotrol methanotrophic bioreactor system was accepted into the EPA's SITE emerging technology program. The Biotrol system was tested at the bench- and pilot-scale levels under the SITE program. One of the objectives of the study was to determine operating costs for parameters that influence the economic competitiveness of the system (D10498D).

Based on actual methane use in the pilot-scale reactor projected methane costs for a large unit were \$0.33 per 1000 gal of water treated. This cost could be reduced by modifications to the system. Calculated theoretical minimum methane costs were \$0.05 per 1000 gal (D10498D).

Information Source

D10498D, U.S. EPA, 1993

T0126

Bioventing — General

Abstract

Bioventing is the in situ process of supplying oxygen to soil to stimulate the aerobic biodegradation of contaminants. It is achieved by forcing air through contaminated soil at low airflow. Because lack of oxygen in contaminated soil can limit aerobic microbial growth, bioventing can increase the rate of biodegradation of organic contaminants by enhancing the growth of microorganisms naturally present in the soil. Bioventing has been commercially available for several years and is available from a variety of vendors.

Bioventing technology is applicable to contaminants in the vadose zone as well as contaminated regions just below the water table. It is applicable for any contaminant that degrades more readily aerobically than anaerobically. Most applications have targeted the less volatile petroleum hydrocarbons, although the technology has also remediated mixtures that include acetone, benzene, toluene, biphenyl, phenol, methylphenol, naphthalene, and polycyclic aromatic

hydrocarbons (PAHs). With proper modifications, bioventing can effectively degrade the more volatile hydrocarbons found in gasoline. Bioventing may be used in conjunction with soil vapor extraction.

Advantages of bioventing include the following factors:

- Works in unsaturated soils
- Comparitively simple design
- Emphasizes biodegradation and minimizes volatilization
- Provides for complete site cleanup by addressing less volatile contaminants as well as volatile organic compounds (VOCs)
- Relatively inexpensive technology

Bioventing remediation may take longer than traditional soil vapor extraction techniques because biodegradation processes inherently take longer than removal techniques that incorporate volatilization and high airflow rates. In addition, soil vapor transport can be severely limited in a soil with high bulk density, high soil water, high non-aqueous-phase liquid content, low porosity, or low permeability. To use bioventing successfully, it is essential that the soil matrix have permeabilities that allow for sufficient air movement.

Technology Cost

Costs for bioventing relate to pre-existing factors that determine the maximum rate of biodegradation at a given site. In addition to the availability of sufficient oxygen, the rate of in situ biodegradation is dependent on site-specific factors including the type and distribution of microorganisms, the bioavailability of target contaminant(s), nutrient availability, and the presence of contaminants that are toxic to the microorganism population. Soil conditions (e.g., soil temperature, soil moisture content, pH, bulk density, and permeability) also impact biodegradation rates. For optimum aerobic metabolism, available soil water should be between 25 and 85% of water-holding capacity; soil pH should be between 5.5 and 8.5, and temperature should be between 15 and 45°C (D14011U, p. 2, 3, 7).

A study completed by Los Alamos National Laboratory in 1996 lists cost information for five full-scale and two pilot-scale bioventing applications. Table 1 lists these sites and the associated costs. Costs range from \$10–15 to \$125/yd^3 remediated (for sites where units are given in cubic yards) (D19347Z, pp. 13–15).

Reisinger et al. have conducted a cost-effectiveness and feasibility comparison of bioventing versus conventional soil venting with either off-gas treatment or direct off-gas discharge. Costs are based on a hypothetical site located in the eastern Piedmont that has sandy silt soils contaminated with weathered gasoline. Results of the analysis for the hypothetical site are given in Table 2. The analysis showed that bioventing is 56% less expensive than soil venting with off-gas treatment but more expensive than conventional soil venting without off-gas treatment. Additional analyses based on two smaller sites are also discussed by Reisinger et al. with similar, though slightly reduced cost differences (D15156E, pp. 54–56).

Downey et al., of Parsons Engineering Science, Inc., reported costs for bioventing at a diesel-fuel-contaminated site in Nebraska as \$112,000, or less than \$10/m^3 of soil treated. This cost included pilot testing, full-scale installation, and 2 years of operation and maintenance but did not include the cost of electricity (estimated at \$280 per month) or labor costs for system checks. It is noted that bioventing provides significant economy of scale and that costs for sites smaller than 11,000 m^3 are typically in the range of \$10 to \$30/m^3 (D151508, p. 124).

Pilot-scale studies were conducted at three petroleum-contaminated sites in Hawaii. The costs for remediation were approximately \$20/m^3 of soil. Long-term operation and maintenance costs are estimated to range from \$1 to \$3/m^3 per year (D14784W, p. 388).

TABLE 1 Treatment Costs for Bioventing Applications

Site Name	Cost Element	Cost	Scale
U.S. DOE Savannah River Site, Aiken, SC	Total capital cost	$150,000	Full
Hill Air Force Base, Utah	Total cost/unit	$10–15/yd^3	Full
Refueling Loop E-7, Source Area ST20, Eielson AFB, Fairbanks, Alaska (thermally enhanced bioventing)	Capital cost Annual O&M Total cost/unit	$758,077 $177,160/yr $10–15/yd^3	Pilot
Underground Storage Tank Site, Lowry Air Force Base, Denver, Colorado	Total capital cost Operating costs	$28,650 $32,875/yr	Full
JP-4 Fuel Spill Site at Site 914, Hill Air Force Base, Ogden, Utah	Total capital cost Operating costs Total treatment	$335,000 $132,000/yr $599,000 ($120/yd)	Full
Hill Air Force Base, Site 280, Ogden, Utah	Total capital cost Operating costs	$115,000 $24,000/yr	Full
Tyndall Air Force Base, Florida	Total cost/unit	$15–20/m^3 ($12–15/yd^3)	Pilot

Source: Adapted from D19347Z.

TABLE 2 Costs Comparison for Bioventing Versus Soil Venting for General Site

	Costs[a] in 1994 Dollars		
Activity	Soil Venting with Direct Off-gas Discharge	Soil Venting with Off-gas Treatment	Bioventing
Pilot testing	$7,500	$10,000	$10,000
Design/permitting	$5,000	$7,500	$5,000
System installation	$14,500	$19,000	$16,000
Startup	$3,000	$6,000	$4,000
Operation (1 year)	$43,300	$148,700	$48,800
Total first-year cost	$73,300	$191,200	$83,800
Estimated time for remediation (days)	400	400	500

Source: Adapted from D15156E.
[a]Costs are based on a generalized hypothetical site with 6000 m^2 of surface area, and a volume of 7200 m^3 contaminated with 82,200 kg of hydrocarbons in the form of weathered gasoline.

Information Sources

D14784W, Ratz et al., 1995

D15156E, Reisinger et al., 1994

D151508, Downey et al., 1995

D19347Z, DuTeaux, 1996

D14011U, Sims et al., 1993

T0127

Blast Fracturing — General

Abstract
Blast fracturing is a technique that is used to increase the hydraulic conductivity of fractured bedrock units containing contaminated groundwater. The technique involves the controlled use of explosives to create localized areas of highly fractured rubble. This area, called the “fracture trench,” acts as a local groundwater sink, minimizing off-site migration. Groundwater is extracted from the fracture trench at higher rates and with greater effectiveness by recovery wells.

Blast fracturing has the following advantages:

- Increases hydraulic parameters such as transmissivity (T) and hydraulic conductivity (K).
- Expands capture radii of pumping/recovery wells, decreasing number of wells needed.
- Increases well yields, which can shorten time required to achieve remediation goals.
- Limits contaminant migration.
- Improves verification of contaminant capture since recovery wells can be directly connected to fractures along the entire cross section of the fracture zone.

Blast fracturing does not destroy contaminants. After blast fracturing, a remediation technology must be applied to the contaminated groundwater. Application of blast fracturing requires an on-site field test of the proposed blasting setup to test the hydrogeological and explosives assumptions on which it is based. Subsurface structures such as buried water mains or pipelines may limit use of blast fracturing technology. Other limitations of the technology include:

- Thickness of overburden
- Positioning of explosives
- Ability of buildings and structures in the area to withstand vibrational impact

Technology Cost
Loney et al. stated in 1996 that the cost for installing an engineered blasted-bedrock zone in the northeastern United States is approximately \$150 to \$250 per linear foot. Thus, installing a 300-ft-long fracture would cost between \$45,000 and \$75,000. Additional costs would be incurred for the installation of collection and treatment equipment. Since the installation of a single conventional recovery well costs between \$8000 and \$15,000, and the authors have provided data that one blast-fractured well may have a recovery ability equivalent to approximately 60 conventional well, a substantial cost savings is possible using this technique. The authors also state that annual operations costs and the potential costs associated with the risk of off-site migration of the contamination are reduced (D170036, p. 199).

Information Source

D170036, Loney et al., 1996

T0128

Bogart Environmental Services, Inc.

Bevrox Biotreatment

Abstract
Bevrox Biotreatment, or “liquid–solids contact (LSC) digestion,” is a patented, ex situ process for the treatment of biodegradable contaminants in soil, groundwater, or process water.

The technology is a slurry-phase biological treatment that, according to the vendor, has successfully treated soil, sludge, groundwater, and process water contaminated with volatile and semivolatile organic compounds (VOCs and SVOCs) such as toluene, naphthalene, fluoranthene, pentachlorophenol, and creosote.

The Bevrox Biotreatment technology consists of three phases: the primary contact, or mixing phase; the primary digestion phase; and the polishing phase. The equipment is mobile and modular; a project may require from 2 to 12 reactors. The technology does not treat metals.

Technology Cost

The vendor estimates the following costs of using Bevrox Biotreatment:

- Operational costs of $5.00/yd^3 of material treated
- Labor costs of $2 to $3/yd^3
- "Very conservative" estimate of utility costs of $10/yd^3.

All costs are directly related to the volume of material treated (D14077C).

Information Source

D14077C, Bogart Environmental Services, Inc., date unknown

T0129

Bogart Environmental Services, Inc.

MiKIE

Abstract

MiKIE is a mobile, modular biological water treatment technology used for the treatment of organic contaminants. The system was developed and patented by John D. Bogart and is commercially available from Bogart Environmental Services, Inc. According to the vendor, the MiKIE system has been in use for water decontamination on several sites for nearly 5 years.

The system uses three main components: an equalization tank (EQ), treatment cells, and a clarification cell. The EQ dilutes the feed stream and begins the biodegradation process. The treatment cells contain media to which the bacteria are attached and the water is passed through each of these cells twice. The cells are aerated to provide the necessary oxygen for the bacteria, and this is where the bulk of the degradation occurs. The clarification cell is where bacteria that have become dislodged from the media are settled out and recycled to the EQ.

The system is designed for treatment of organic contaminants only.

Technology Cost

Costs vary among units based on the specific configuration required at the site. Operating costs are also dependent upon the unit's configuration. Costs have been tracked for a 15,000-gal, 10-horsepower unit. Over the expected life of the unit costs are between $.60 and $1.00 per thousand gallons treated. This price includes oversight, power, biomass maintenance, and capital amortization (D14819Q, p. 2).

Information Source

D14819Q, vendor information

T0130

Bohn Biofilter Corporation

Bohn Off-Gas Treatment

Abstract
Biofiltration is the sorption of volatile organic gases (VOCs) from contaminated air by beds of compost or soil and the oxidation of the sorbed materials by existing microorganism populations. Biofilters can treat pollutant gases from food and waste processing, petroleum refining, chemical processing, tank vents, and polishing of air after solvent recovery.

Both permanent and portable biofilters are commercially available from Bohn Biofilter Corporation for on-site oxidation of off-gas contaminants. More than 20 permanent biofilter beds are in use in the United States ranging in flow rates from 200 to 300,000 cubic feet meters (cfm) along with 500 permanent biofilters operating in western Europe and Japan.

According to the vendor, biofilters require little or no maintenance. Microbial productivity is primarily limited by moisture and temperature levels. Input gases must be maintained within certain moisture and temperature parameters for the effective oxidation of contaminants.

The vendor claims the following advantages for the technology:

- It consumes no fuel or chemicals.
- Creates no secondary pollution.
- Requires less maintenance than other technologies.
- Creates no fire or chemical hazards.
- Adapts to a wide variety of air pollutants.
- Adapts to a wide degree of destruction efficiencies.

Technology Cost
The vendor estimates the treatment cost with a biofilter at $5 to $10/kg of waste. Factors that have a significant effect on the unit price are the quantity of waste, the target contaminant concentration, the initial contaminant concentration, and the targeted final concentration of the treated contaminant. These price estimates do not always include all indirect costs (D10048R, p. 28).

In comparison to other air pollution control technologies, biofiltration is one of the most affordable technologies on the market (D14012V, p. 37). Table 1 compares the costs of various off-gas treatment technologies.

TABLE 1 Cost Comparison of Air Pollution Control Technologies (1991 U.S. dollars)

Technology	Total Cost ($) per 10^6 ft^3 of air[a]
Incineration	130
Chlorine	60
Ozone	60
Activated carbon (with regeneration)	20
Biofiltration	8

Source: D14012V, Bohn, 1992.
[a]Costs obtained from B. Jaeger, and J. Jeger, “Geruchsbekaempfung in Kompostwerken am Beispiel Heidelberg,” Muell und Abfall, pp. 48–52 (Feb. 1978) and converted/updated to 1991 U.S. dollars.

T0131

Brice Environmental Services Corporation (BESCORP)

BESCORP Soil Washing System (BSWS)

Abstract

The BESCORP Soil Washing System (BSWS) is a water-based unit for the volume reduction of coarse/sandy soils contaminated with lead or other heavy metals. It uses a combination of trommel agitation, attrition scrubbing, high-pressure washing, and separation by particle size and density to remove heavy metals and heavy-metal compounds from soil.

This soil washing process creates three soil fractions: oversize, sand, and fines. The goal of soil washing is normally to produce two clean fractions and concentrate the contaminants into the fines fraction. From this point, various techniques may be used to remove the contaminant(s), depending on its specific characteristics.

The BSWS is applicable to soils containing battery casings, casing chips, or metallic lead. Much of the lead removal is achieved by separation of the battery casings, and metallic lead from the feed soil. Typically, the heavy metals concentrate in the fines fraction of the soil (less than 150 mesh), and the BSWS separates this fraction from the more coarse soil fractions.

The BSWS performed a Superfund Innovative Technology Evaluation (SITE) demonstration at a lead battery recycling site in Fairbanks, Alaska. It was also used in conjunction with COGNIS Incorporated's Terramet leaching and recovery technology (RIMS technology T0207) in a full-scale demonstration at the Twin Cities Army Ammunition Plant in Minnesota, where the BSWS was used as a pretreatment step for size separation and to reduce the load to the Terramet leaching/recovery technology (currently the Terramet technology is owned by the Doe Run Company).

The effectiveness of the BSWS as a volume reduction unit depends largely on the solubility of the lead compounds in the washing medium, the efficiency of density separation for removing discrete lead particles, and the particle size distribution in the feed soil.

The BSWS technology has been used in full-scale cleanups and is commercially available.

Technology Cost

For a commercial 20-ton/hr BESCORP Soil Washing System (BSWS) unit, operating costs would be around \$165 per ton of soil. This estimate is based on conditions similar to those used in the U.S. Environmental Protection Agency's (EPA's) SITE demonstration, with soil having 6.6% moisture, by weight (D10427Y, p. iv). This estimate also assumes remediation of 30,000 yd^3 or 56,362 tons of soil, and an on-line factor of 80% (D10427Y, pp. 4, 20). This cost estimate was extrapolated from a demonstration involving 46 tons of soil at 2.4 to 4.2 tons/hr. Scale-up risk to a 20-ton/hr unit is minimal (D10427Y, pp. 1, 4).

Total costs for that site would be \$9.3 million, whereby 85% of the costs associated with the process derive from disposal of the solid waste streams, and labor represents 12% of the total costs (D10427Y, p. 29). A detailed breakdown of costs is available on page 25 of document D10427Y.

The resale value of the recovered product is not expected to be a significant factor in cost calculation. At best, resale of the product will reduce the overall cost of the process enough to keep it competitive with other remediation technologies (D11846H, p. 976).

At a demonstration site at Fort Polk, Louisiana, BSWS costs were \$1400/ton for the 835 tons of soil treated. Fixed costs were high at this site (\$830/ton); however, it is estimated that these costs would decrease significantly for a full-scale operation. Based on the results of this demonstration, costs for a full-scale operation treating 10,000 tons of soil would be approximately \$170/ton. Fixed costs were estimated to be \$70/ton (D200953, p.1).

Information Sources

D10427Y, U.S. EPA, 1995
D11846H, Royer et al., 1992
D200953, ESTCP, 1997

T0132

Brookhaven National Laboratory

Biochemical Recovery of Radionuclides and Heavy Metals

Abstract
Brookhaven National Laboratory's (BNL's) biochemical recovery of radionuclides and heavy metals is a patented biochemical recovery process for the removal of metals and radionuclides from contaminated minerals, soil, and waste sites. In this process, citric acid, a naturally occurring organic complexing agent, is used to extract metals and radionuclides from solid wastes by the formation of water-soluble, metal–citrate complexes. The complex-rich extract is then subjected to microbiological biodegradation that removes most of the extracted heavy metals.

Following biological degradation, the extract is exposed to photochemical degradation, which removes uranium from solution as polyuranate. The metals and uranium are captured in separate treatment steps, allowing for the separation of wastes into radioactive and nonradioactive waste streams. This treatment process does not create additional hazardous wastes and allows for the reuse of the contaminated soil. The technology has been the subject of bench-scale tests and is not currently commercially available.

Researchers at BNL claim that this technology may be used to extract metals such as cadmium, arsenic, lead, zinc, copper, magnesium, manganese, aluminum, barium, nickel, and chromium, as well as radionuclides such as uranium, thorium, plutonium, cobalt, cesium, and strontium. They state that the process offers the following advantages:

- Is only known technology capable of greater than 99% uranium removal
- Allows important metals to be removed and recovered, while causing little damage to treatment soil.
- Separates mixed waste into radioactive and nonradioactive components, reducing treatment and disposal costs.

Metals associated with organic materials, inert compounds, or iron oxides may not be recovered during the extraction phase of the technology. Complexed hexavalent uranium has been shown to inhibit the growth of one strain of bacteria used for remediation. The effect becomes more pronounced at higher concentrations of uranium.

Technology Cost
There is no available information regarding the costs associated with this technology.

T0133

C.E. Rogers Company

Mechanical Vapor Recompression (MVR) Evaporator

Abstract
The mechanical vapor recompression (MVR) evaporator uses a turbofan compressor to evaporate water that separates the water from dissolved solids. The MVR system discussed in this

technology summary is available from C.E. Rogers Co. and has been implemented in full-scale industrial settings.

This technology does not change any hazardous characteristics of the waste; it creates a more concentrated waste for further treatment or disposal.

Technology Cost

Table 1 lists vendor-supplied costs for a C.E. Rogers Co. (MVR) evaporator system able to treat 120,000 gal per day. Table 2 gives C.E. Roger's cost comparisons between the MVR system

TABLE 1 Vendor-Supplied MVR Costs at 120,000 gal/day

Capital Cost	
Equipment	$750,000
Engineering and installation	$80,000
Extras (freight)	$7,900
Total bid	$837,900
Tax (0.0725%)	$54,375
Building	$20,000
Equalization tank	$50,000
Tankage	$15,000
Foundations	$85,000
Total capital cost	$1,062,275
Operating Cost ($/month)	
Electric @0.08/kWh	$15,600
Operators @$30/hr	$7,300
Waste hauling @$65/hr	$7,908
Steam @$0.37/therm	$1,216
Total operating & maintenance ($/month)	$32,024
Total operating & maintenance ($/year)	$384,292

TABLE 2 Vendor's Cost Comparison of MVR versus Membrane Filtration

	MVR	Membrane Filtration System 1	Membrane Filtration System 2
Total capital cost	$1,062,275	$845,273	$1,054,423
Total operating & maintenance ($/month)	$32,024	$58,157	$42,032
Total operating & maintenance ($/year)	$384,292	$697,878	$504,381

TABLE 3 Vendor-Supplied Costs per Hour for MVR Units

Unit	Electrical (@ $0.06)	Steam	Total Cost
50 gal/min, 158 kW	$9.48	$2.00	$11.48
100 gal/min, 278 kW	$16.68	$4.00	$20.68
150 gal/min, 415 kW	$24.90	$6.00	$30.90
200 gal/min, 555 kW	$33.30	$8.00	$41.30

and two membrane filtration systems. Table 3 gives the vendor's costs per hour of four different MVR units capable of treating 50, 100, 150, and 200 gal/min.

Information Source

D16621M, vendor literature

T0134

CAE Alpheus Inc.

Carbon Dioxide Blasting

Abstract
Carbon dioxide (CO_2) blasting is a technology in which solid CO_2 particles are propelled by compressed air at high velocities to impact and clean a surface. Once the dry ice hits the surface to be cleaned, it sublimates, or transforms directly from a solid to a gas. This transformation creates a "gas wedge" that lifts and shears the contaminant or coating. The technology has been used in industrial cleaning applications since 1987 and is commercially available as a decontamination technology to remove hazardous or radioactive contaminants from surfaces.

According to information published by the U.S. Navy in 1996, carbon dioxide cleaning offers the following advantages:

- Significant reduction in the amount of hazardous waste and hazardous air emissions compared to chemical stripping.
- A 80 to 90% reduction in time required for cleaning/stripping processes.
- No residue left on the component surface.
- Effective in precision cleaning.
- No new contaminants are introduced.

Most surfaces cannot be etched or profiled using CO_2. If large quantities of small parts need cleaning, CO_2 is not as efficient as other alternatives such as ultrasonics. The noise level during operation can range from 85 to 130 decibels (dB), so hearing protection is required. If the application does not require online cleaning, CAE Alpheus Inc. offers a blast booth that offers 40 dB of noise attenuation that brings levels within the Occupational Safety and Health Act (OSHA) unprotected standards at blast pressures of up to 225 pounds per square inch (psi).

Although CO_2 is a nonreactive gas, it is an asphyxiant and should only be used in areas with adequate ventilation. Static energy can build up during treatment, so CO_2 blasting should not be done in flammable or explosive atmospheres. CO_2 blasting is generally not a one-pass procedure, and multiple passes are often required to achieve the preferred result. CO_2 blasting does not destroy hazardous contaminants, they must be collected and disposed of. Blasting a fixed position for a long period of time can damage substrate material. The technology is also ineffective for cleaning thin materials, which can be damaged by the process. Additional limitations may include the need for operator training, high capital costs, and operator safety issues.

Technology Cost
According to an undated report produced by the Northeast Waste Management Officials' Association (NEWMOA) and the U.S. Environmental Protection Agency (EPA), CO_2 pellet blasting units can range from \$25,000 to \$50,000. Units can also be rented, with monthly payments costing between \$1500 and \$2500. In addition, pellet blasting performed on a contract basis can range from \$200 to \$300 per hour. Contract costs take into account labor, pellet, and equipment costs, but not travel expenses (D21488K, p. 25).

The report produced by NEWMOA and U.S. EPA also notes that CO_2 snow-blasting units are much cheaper to purchase and operate than pellet-blasting units. On average, manual snow-blasting units cost about \$2000. Semiautomated units are more expensive, ranging from \$3000 to \$5000; however, these units can be used in assembly applications. CO_2 purifiers are also available that can increase the quality of cleaning. These units cost about \$5000 (D21488K, p. 27).

In a 1992 report for the U.S. Department of Energy (DOE) facility at Rocky Flats, it was estimated that the cost of operating the Alpheus carbon dioxide pellet system in a mixed waste removal application would be approximately \$297 per hour. It was estimated that if the system was able to clean 100 lb of material per hour, the cost of cleaning a standard 5000 lb of material would be \$14,850. This would be less than the cost of shipping the material for cleaning at another facility using conventional methods (D15087I, p. 4). A breakdown of the cost analysis for running a CO_2 blaster with in-house equipment is given in Table 1.

Initial capital costs for the Alpheus Model 250 and support equipment used during this experiment are as follows: Alpheus Model 250, \$107,000; compressor, \$81,000; CO_2 storage tank, \$46,000; air dryer, \$21,000. Total capital costs were listed at \$255,000 (D15087I, p. 10).

Costs for industrial CO_2 cleaning systems have dropped over the last few years. When the first CO_2 blasting machines were produced in the late 1980s, systems cost up to \$250,000 and weighed nearly 2000 lb. In 1997, Alpheus released information stating that the cost of a portable CO_2 MiniBlast™ Model SDI-5 system for industrial cleaning was approximately \$30,000 (D17262N, p. 14).

The vendor states that the most notable operating costs of CO_2 blasting are associated with providing the compressed air and dry ice. Costs for dry ice average about \$0.25/lb for both

TABLE 1 Cost Analysis for Running a CO_2 Blaster with In-House Equipment

Cost Category	Total
Blaster usage costs	
Cost of electricity (per kWh)	\$0.04
Power usage of blaster (kW)	17 kW
Electricity costs/hr	\$0.68
Average cost of liquid CO_2 (per lb)	\$0.07
Average amount of CO_2 used (lb/hr)	250 lb/hr
CO_2 costs/hr	\$17.50
Subtotal	\$18.18
Compressor usage costs	
Average cost of diesel fuel (per gal)	\$1.11
Average amount of diesel fuel used (gal/hr)	14 gal/hr
Safety factor of estimating	1.5
Compressor fuel usage costs/hr	\$23.31
Subtotal	\$23.31
Labor cost	
Number of people needed to clean material	2
Foreman	1
RPT coverage time	\$0.25
Average pay per person (per hr)	\$78.50
Labor costs/hr	\$255.12
Subtotal	\$255.12
Total costs/hr	\$296.70

Source: Adapted from D15087I.

blocks and pellets. Prices vary from region to region and are seasonal. An industrial customer of Alpheus estimated that the hourly cost of operating a commercial full-scale unit are about $24.00 (based on 120 lb of dry ice used per hour at $0.20/lb). The other assumptions on which this estimate was based were not provided (D17262N, p.16).

Information Sources

D15087I, Knight and Blackman, 1992

D17262N, vendor web page, 1997

D21488K, Northeast Waste Management Officials' Association (NEWMOA) and U.S. EPA, undated report

T0135

Calgon Corporation

Activated Carbon

Abstract

Calgon Corporation offers several activated carbon adsorption systems. Activated carbon is an amorphous form of graphite consisting of a random series of graphite plates. The structure is highly porous, possessing a variety of cracks and crevices with openings that reach molecular dimensions. Larger openings function as transport pores that allow contaminants to diffuse to the adsorption sites or pores, which make up about 40% of the particle's volume. Activated carbon acts as an adsorbent, meaning that it attracts and holds molecules to its surface.

The vendor states that activated carbon systems can be used on liquid, vapor, and solid waste streams contaminated with organic materials. Calgon Chemical Corporation has patented activated carbon technology. The vendor states that they produce more than 40 specialized types and sizes of bituminous coal- and coconut-based activated carbons for over 700 applications.

Calgon claims the following advantages for its activated carbon systems:

- Modular systems are available to meet site requirements.
- Facilities are available for disposal and regeneration of spent activated carbon, and the vendor can coordinate transportation and on-site exchange requirements.
- Technology has been used for years and has proven to be reliable.
- The technology allows for waste minimizing and materials recycling.

The following factors may limit the effectiveness of activated carbon treatment:

- Relative humidity greater than 50% can reduce carbon capacity in vapor-phase adsorption.
- Elevated temperatures from soil vapor extraction (SVE) pumps (greater than 100°F) can inhibit adsorption capacity.
- Biological growth on carbon or high particulate loadings can reduce flow through the bed.
- High amounts of suspended solids or oil and grease can cause fouling of the carbon requiring frequent backwashing.
- High levels of organic matter (>1,000 mg/liter) can rapidly exhaust carbon.
- Spent carbon transport may require hazardous waste handling.
- Spent carbon requires additional treatment before disposal.
- Some compounds, such as ketones, may cause carbon bed fires because of their high heat release upon adsorption.

Technology Cost

The vendor states that treatment costs for activated carbon treatment will vary widely depending on site-specific requirements such as the type of contaminants and the desired treatment rate. For permanent systems, the cost of carbon replacement can vary between $0.80 and $1.50 per pound, depending upon the type of carbon used in the replacement (virgin or reactivated), job distance from Calgon carbon's reactivation center, and the type of transport required (D15749X, p. 10).

Equipment cost for industrial activated carbon systems were provided in undated vendor material. The Model 4 system contains two 4-ft-diameter adsorbers and contains 2000 lb of granular activated carbon. The Model 8 system has two 8-ft-diameter adsorbers and contains 6000 to 10,000 lb of granular activated carbon. The Model 10 system has two 10-ft-diameter adsorbers, and the Model 12 system contains two 12-ft-diameter adsorbers. Both units contain 20,000 lb of granular activated carbon (D15749X, pp. 19–22). Estimated capital costs for the systems are given in Table 1.

Costs for some portable canister systems are given in Table 2.

TABLE 1 Calgon Carbon Estimated Capital Costs for Permanent Activated Carbon Systems (all costs are given in dollars)

		Cost of Initial System Fill with Activated Carbon		
System Number[a]	Equipment Cost[b]	F-300[d]	Reactivated	Installation Costs[c]
Model 4	$40,000	$4,000	$2,800	$500
Model 8	$75,000	$20,000	$14,000	$4,000
Model 10	$110,000	$40,000	$28,000	$7,000
Model 12	$130,000	$40,000	$28,000	$9,000

Source: Adapted from D15749X.

[a]Model 4 system described contains steel pipes. Model 10 system described is backwashable. Systems include all piping and manual valves to comprise a complete adsorption system, enabling all operations.

[b]Equipment costs include drawings, technical submittals, and provision of an operation and maintenance manual. Freight cost may need to be added for some models.

[c]Costs for installation supervision, startup, and training services are not included.

[d]F-300 is virgin grade type Filtrasorb 300 granular activated carbon.

TABLE 2 Estimated Capital Cost Ranges of Calgon Carbon Canister Systems

Type of Canister[a]	Cost Range (in dollars)[b]
Liquid-Phase Waste Treatment Units	
1000 lb	$5000–$6000
2000 lb	$7000–$8000
Vapor-Phase Waste Treatment Units	
1000 lb	$6000–$7500
2000 lb	$7000–$8500

Source: Adapted from D15749X.

[a]This estimate is for nontransportable canisters; coated. cor-pressure carbon steel adsorbers, with no additional piping supplied.

[b]The cost range depends on carbon type used: virgin or reactivated.

Information Source

D15749X, Calgon Corporation, undated vendor literature

T0136

Calgon Carbon Oxidation Technologies

Rayox

Abstract
Rayox® is an ex situ enhanced oxidation technology for the treatment of groundwater and process wastewaters containing organic contaminants. The technology uses ultraviolet (UV) light and oxidants such as hydroxyl radical, hydrogen peroxide, or ozone to destroy contaminants. Rayox is patented and commercially available. The technology has been implemented at many sites and has proven to be effective at treating many volatile organic compounds (VOCs), including vinyl chloride (VC), dichloroethylene (DCE), trichloroethylene (TCE), pentachlorophenol (PCP), as well as benzene, toluene, ethylbenzene, and xylenes (BTEX). Some semivolatile organic compounds (SVOCs) can also be treated using the technology.

According to the vendor, the Rayox process has the following advantages:

- Contaminants can be treated on-site, eliminating the need for secondary handling and disposal.
- When used to treat bromide-ion bearing waste, the process will not produce bromite ion.
- No secondary wastes or off-gases are produced, and oxidation by-products are nontoxic.
- The process works at ambient pressure and temperature.
- The equipment is quiet and compact.
- Maintenance and operating requirements are minimal.
- The process is cost effective for a variety of contaminants.
- The process can be combined with other treatment technologies.

The Rayox process has several potential limitations. If oxidation reactions are not completed during treatment, residual hazardous compounds may remain in the waste stream. Incomplete oxidation may result from an insufficient quantity of oxidizing agent, low or high pH, the presence of interfering compounds that consume reagent, or inadequate mixing or contact time. If ozone is used in the Rayox process, off-gases may also require treatment for stripped VOCs or residual ozone. In addition, the enhanced oxidation process is not cost effective for treating highly concentrated wastes because of the large amounts of oxidizing agent(s) required.

Technology Cost
The vendor claims that the capital costs for Ultraviolet (UV)/oxidation are typically 2 to 3 times higher than for activated carbon. In this context, longer term projects favor UV/oxidation because the cumulative savings in operating costs offset the higher capital expenses. For contaminant concentrations below 10 parts per million (ppm), activated carbon may provide a more cost-effective treatment option (D17097S, pp. 3–7).

In 1994, Rayox developers generated cost estimates for the technology based on bench-scale studies. Using a proposed cleanup site in Canada as a model, researchers compared these estimates with the costs of using an air stripper/liquid carbon/catalytic oxidizer (air/carbon) option. Results indicated that UV/peroxide treatment, with or without an iron catalyst, was found to have an estimated capital cost equal to the air/carbon option at the site (D12302U).

Operating costs for the two options, however, were found to be significantly different. Preliminary cost estimates indicated that the air/carbon option had a much lower operating cost at high influent toluene concentrations, which would be expected at the start of treatment. Operating costs for air/carbon treatment remained steady even when influent toluene concentrations significantly decreased. In contrast, UV/peroxide treatment costs were found to decrease as toluene concentrations decreased. Therefore, the cost effectiveness of using either option for a full-scale treatment at the proposed site would depend on the rate of toluene concentration decline, which at this site would be increased with the aid of vapor-phase extraction and/or free-product removal. Additional cost comparisons are presented in Table 1 (D12302U).

Vendor-supplied cost information for the Rayox technology is presented below:

- At the Brown and Bryant Superfund Site, in Arvin, California, soil washing operations resulted in the production of 100,000 gal of wash water containing 400 to 600 ppm of Dinoseb. A Rayox system was implemented at the site that used ozonation followed by UV/peroxide treatment. The operating cost for this project was $40 per 1000 gal (D17097S, Appendix II).
- Two Rayox units were installed for full-scale treatment of TCE and DCE at Kelly Air Force Base in San Antonio, Texas, in 1993. Operating costs, including maintenance, were approximately $1.34 per 1000 gal for the 90-kW system, and $1.98 per 1000 gal for the 270-kW system (D135159).
- In 1993, a 60-kW system was used at a wood treating facility in Missouri to treat groundwater contaminated with PCP. This unit had operating costs of $1.30 per 1000 gal of water treated (D135159).
- In 1994, a Rayox system consisting of nine 30-kW reactors was installed at a polyester plant in Salisbury, North Carolina. The system treated groundwater contaminated with 1,4-dioxane and biphenyl ether. The operating cost for the system was $0.76 per 1000 gal of water treated (D135159).
- At a service station in Carson City, Nevada, a 30-kW Rayox system was used to treat groundwater contaminated with BTEX and petroleum hydrocarbons. Operating costs for this system were $2.25 per 1000 gal of water treated (D17097S, Appendix II).
- NASA has used Rayox to treat hydrazine in wastewater produced by space craft fueling operations. Previously, this wastewater had been shipped off-site for treatment at a cost of $3 to $4 per gallon. The use of Rayox on-site cut costs to approximately $0.30 per gallon (D22281B, p. 1).
- A Rayox system was used with granular activated carbon (GAC) treatment at Fort Ord in Monterey, California. This hybrid system was implemented at the site to treat groundwater

TABLE 1 Operating Costs as a Function of Influent Toluene Concentrations (1994)

	Canadian $per 1000 Imperial Gallons				Canadian $per Year			
Treatment	1 ppm[a]	10 ppm	100 ppm	300 ppm	1 ppm	10 ppm	100 ppm	300 ppm
UV/peroxide	4.0	5.4	16.7	29	5,300	7,100	22,000	38,300
UV/peroxide (iron catalyst)	4.3	5.1	10.3	17	5,700	6,700	13,600	22,400
Air stripper/liquid phase carbon/catalytic oxidizer	7.6	7.6	7.6	7.6	10,000	10,000	10,000	10,000

Source: Adapted from D12302U, p. 148.

[a] ppm = parts per million toluene.

contaminated with DCE, TCE, and methylene chloride. Operating costs for the system were $1.12 per 1000 gallons of water treated (D22285F, pp. 1, 2).

- At a site in Puerto Rico, a 30-kW Rayox-F (UV/fenton) unit was used in an industrial wastewater application to treat chemical oxygen demand (COD). The unit, which had a flow rate of 1 m^3/day, had an operating and maintenance cost of $44.32/$m^3$ (D22279H, p. 2).
- Calgon Corporation will install and operate a Rayox system in Covina, California, for a contract price of $565,000 (1999 dollars). The 3000 gallon per minute (gpm) system will treat groundwater contaminated with *N*-nitrosodimethylamine (NDMA) (D197233, p. 1).

According to the U.S. Navy, a UV/peroxide system capable of treating 200,000 gallons of wastewater per day has a capital cost between $100,000 and $200,000. Operational costs for a 100,000-gal per day UV/peroxide treatment facility run between $3000 and $10,000 per day (D197186, p. 2).

The Salt Lake City Department of Public Utilities in Utah installed a 360-kW unit to treat tetrachloroethene (PCE) in drinking water. The capital investment for the project was $450,000 (1998 dollars). Operating costs for the system were less than $0.20 per 1000 gal of treated water (D197211, p. 1).

A pilot-scale Rayox system, which included a GAC treatment component, was installed at the Charnock Wellfield site in Santa Monica, California. Groundwater at the site was contaminated with methyl tertiary butyl ether (MTBE) and tertiary butyl alcohol (TBA). Capital costs for the proposed 3500 gpm full-scale system are projected to be $4 million to $5 million. These costs do not include expenses associated with installing the technology or purchasing property to house the system (40,000 ft^2 are required). Operating costs are projected to be $1.50 to $1.75 per 1000 gal of water treated (D22276E, pp. 50, 51).

Information Sources

D12302U, Notarfonzo et al., September 1994
D135159, Calgon Carbon Oxidation Technologies, undated
D17097S, Calgon Carbon Corporation, undated
D197186, Joint Service Pollution Prevention Opportunity Handbook, 1997
D197211, Calgon Carbon Corporation, 1998
D197233, Calgon Carbon Corporation, 1999
D22276E, U.S. EPA, 2001
D22279H, Vert Tech LLC, 2000
D22281B, Calgon Carbon Corporation, 2000
D22285F, Calgon Carbon Corporation, 2000

T0137

Calgon Carbon Oxidation Technologies

Solaqua

Abstract

Solaqua® is a patented, ex situ process for the removal of organic contaminants from wastewater or groundwater. The technology uses ferric oxalate and hydrogen peroxide in the presence of light to produce hydroxyl radicals, which destroy organic contaminants such as aromatic hydrocarbons, phenols, alkanes, alkynes, ethers, and ketones. Solaqua is not yet commercially available.

Unlike conventional ultra violet (UV)/oxidation technologies, which employ UV lamps, Solaqua can utilize sunlight to trigger the formation of hydroxyl radicals. Hydrogen peroxide or ozone, used with UV lamps to produce hydroxyl radicals in traditional processes, are ineffective adsorbers of solar radiation. For example, Fenton's reagent (hydrogen peroxide and a ferrous salt) is an effective producer of hydroxyl radicals. Fenton's reaction is enhanced by artificial UV light but is not significantly affected by sunlight. Solaqua, however, utilizes either sunlight or artificial UV light to provide a continuous source of hydroxyl radicals.

Titanium dioxide, which is known to be effective in solar detoxification, only adsorbs about 3% of solar radiation and has a low yield of hydroxyl radicals. Solaqua has been demonstrated to be at least 25 times more effective for the destruction of organic molecules than sunlight/titanium dioxide.

When sunlight is used, the rate of contaminant destruction is lower on cloudy days than on sunny days.

Technology Cost
No information available.

T0138

Calgon Carbon Corporation

Perox-Pure

Abstract
The Perox-Pure™ technology is an ultraviolet light (UV)/oxidation process that combines UV light and the chemical oxidant hydrogen peroxide (H_2O_2) to destroy dissolved organic contaminants in water. The process is capable of treating water or leachate contaminated with volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), pesticides, solvents, herbicides, total petroleum hydrocarbons (TPH), explosives, chemical and biological oxygen demand (COD and BOD), and benzene, toluene, ethylbenzene, and xylene (BTEX). Perox-Pure is a full-scale, commercially available technology.

The Perox-Pure system is most effective in treating water with contaminant concentrations less than about 500 mg/liter. Removal efficiencies are high for organic compounds with double bonds (e.g., trichloroethylene, perchloroethylene, and vinyl chloride) and for aromatic compounds (e.g., phenol, benzene, and toluene). These compounds are easily oxidized. The Perox-Pure system can be used alone or in combination with other remedial technologies, such as air stripping.

Because advanced oxidation processes are based on hydroxyl free-radical chemistry, chemical interactions are highly nonselective. Rates of destruction vary with such factors as the nature of the contaminant mixture, pH, concentration of contaminants, presence of scavengers, and inorganic nature.

Oxidation processes do not work well in the presence of free-radical scavengers that consume the ozone and hydrogen peroxide and inhibit the effect of the UV radiation. The presence of such scavengers requires higher doses of oxidizers and larger UV fluxes.

Another important factor is the penetration of UV light through the wastewater stream. Light penetration is weakened by high particle concentrations. Consequently, the technique, in general, is not well suited to treating soils.

Technology Cost
The total remediation cost for a Perox-Pure system depends on specific site and operating conditions including the type and concentration of the contaminant, the presence, type, and

concentrations of other dissolved species, the turbidity or color of the water to be treated, the presence of hydroxyl scavengers, pH, temperature of the system, hydrogen peroxide dosage, power consumption and flow rate of the unit, retention time, use of treatment catalysts, and the treatment mode. The UV operating cost, chiefly from power consumption, can be very high if a long retention time is required for treatment (D123262; D17232H, p. 2).

The capital cost for the Perox-Pure system is between $100,000 and $200,000 for a 200,000-gal per day treatment facility. Equipment capacities can range up to several thousand gallons per minute. The operational costs for the 100,000 gal per day treatment facility vary between $3000 and $10,000 (D17232H, p. 2).

A U.S. Environmental Protection Agency (EPA) cost analysis indicated that the groundwater remediation cost for a 50-gal/min (gpm), 5-kW Perox-Pure system would range from $7 to $11 per 1000 gal depending on contaminated groundwater characteristics. Of this total cost, the Perox-Pure system direct treatment cost would range from $3 to $5 per 1000 gal. The EPA analysis was based on operation of the system for a period of 10 years to treat a total of 26 million gallons of contaminated groundwater (D10057S, pp. 21–27).

During the demonstration at Kelly Air Force Base, capital costs were $115,000 for a 490-liter/min Perox-Pure unit at Site E-1 and $241,000 for a 940-liter/min system at Site E-3. Based on a retention time of 2 min and a hydrogen peroxide concentration of 50 mg/liter, the operation and maintenance (O&M) costs at the E-1 Site were $2800 per month. At the E-3 Site, the Perox-Pure unit operated using a hydrogen peroxide concentration of 100 mg/liter and a retention time of 4 min. The O&M costs were $13,000 per month. O&M costs for both sites included all required chemicals but excluded the costs associated with pretreatment and groundwater extraction systems (D19079Y, p. 3–3).

In 1989, a 510-liter/min Perox-Pure system used 15 kW of power to remove trichloroethene (TCE) from groundwater at a municipal drinking water well in Arizona. The O&M costs were estimated to be approximately $0.28 per 1000 gal of water treated. Based on a price of $0.06/kWh, the unit consumed $0.11 of electricity to treat 1000 gal of drinking water. A 50% hydrogen peroxide solution at a price of $0.35/lb was added to the system. For each 1000 gal of treated water, hydrogen peroxide contributed $0.12 to the total costs. Maintenance requirements were estimated at approximately $0.05 per 1000 gal of water (D19079Y, p. 3–3; D10057S, p. 60).

A 135-gpm Perox-Pure system was used to remediate pentachlorophenol-contaminated groundwater at a chemical manufacturing plant in Washington State. The total O&M costs per 1000 gal of treated water were $3.90, which included $2.57 for electricity (at $0.06/kWh), $0.87 for hydrogen peroxide (at $0.35/lb), $0.03 for acid (at $0.085/lb), and $0.43 for maintenance (D19079Y, p. 3–8; D10057S, pp. 60, 61).

At the former Nebraska Ordnance Plant in Mead, Nebraska, a 29,000-liter/min Perox-Pure unit used 30 kW of power to treat groundwater contaminated with cyclonite (RDX). O&M costs including power, lamp replacement, and hydrogen peroxide were approximately $\$0.02/m^3$ (D19079Y, p. 3–13).

In 1992, industrial wastewater containing isopropyl alcohol and acetone from the Kennedy Air Force Base was treated using at 5-gpm Perox-Pure™ unit. Total O&M costs for the system were $3.60 per 1,000 gallons of wastewater treated. These costs included $2.00 for electricity priced at $0.06 per kW-hour, $0.60 for hydrogen peroxide priced at $0.35 per pound, and $1.00 for maintenance (D10057S, p. 59 & 60; D19079Y, p. 3–21; D17231G, p. 410).

An evaluation of pesticide-contaminated groundwater treatment using a Perox-Pure Model SQ-SA System indicated that the costs to treat a gallon of 10 parts per million (ppm) captan, 2 ppm pentachloronitrobenzene, and 10 ppm propazine were $0.028, $0.044, and $0.109, respectively. This estimate assumed a 5500-W power consumption. This evaluation noted that the hydrogen peroxide contributes only 4% to the total cost of operating this model (D125337, p. 1). These costs were calculated for the treatment of 8 gal of waste and are considerably higher than commercial units due to the volumes treated and the relative capital costs of the equipment (D12536A, p. 26).

TABLE 1 Cost Estimates for Perox-Pure at Four Mixed Waste Sites

Site, Year, Medium	Unit Size (kW)	Flow Rate (gal/min)	Cost ($per 1000 gal)
EG&G Rocky Flats, Inc., 1988 groundwater	240	30	$9.60
Puget Sound Naval Shipyard, 1992, wastewater	60	5	$1.30
Hanford Energy Works, 1992, wastewater	360 (two units)	173	$5.00
National Institute of Health Facility, 1994, wastewater	180	0.3	$0.48

Source: From D125359.

Total O&M costs for bench-scale tests on TCE-contaminated groundwater from an industrial site in the southeastern United States were $1.07 per 1000 gal of treated groundwater. This figure included $0.53 for electricity priced at $0.048/kWh and $0.54 for hydrogen peroxide priced at $0.65/lb. The Perox-Pure used 30 kW to treat 15 gpm of contaminated groundwater (D17231G, pp. 405, 408).

At an electronics manufacturing plant in the southwestern United States, a 30-kW Perox-Pure unit treated 20 gal of groundwater contaminated with TCE, tetrachloroethene (PCE), and dichlororethene (DCE) per minute. The O&M costs for these bench-scale tests were estimated to be $1.29 per 1000 gal. Electricity priced at $0.05/kWh contributed $0.75 per 1000 gal of treated groundwater. Based on a cost of $0.65/lb, the addition of hydrogen peroxide cost $0.54 per 1000 gal of water (D17231G, pp. 405, 406, 409).

The vendor presented cost estimates for treating mixed organic/radioactive wastes in groundwater or wastewater at four sites. Information on the unit size, flow rates, and costs are listed in Table 1 (D125359). Additional information on these sites is provided in the Case Study Overview.

Information Sources

D10057S, U.S. EPA, 1993

D123262, Sirabian, et al., 1994

D125337, U.S. EPA, 1991

D125359, Prellberg et al., 1995

D12536A, Winterlin, 1987

D17231G, Miller et al., 1994

D17232H, U.S. Navy, 1995

D17233I, Calgon Carbon Corporation, 1996

D19079Y, U.S. EPA, 1998

T0139

Cancrete Environmental Solutions Inc.

Depocrete

Abstract

Depocrete™ is a stabilization/solidification process designed for use with organic or metal wastes. According to the vendor, the end product can be recycled or reused in industrial

applications such as flooring, filler, and road bed. Depocrete stabilization/solidification technology is a proprietary process of Heidelberger Zemet, one of the world's largest cement conglomerates, and is exclusively licensed to Cancrete™ for the North American marketplace. Cancrete has actively pursued demonstration projects with the assistance of the Industrial Research Council Assistance Program, National Research Council, and Atlantic Opportunity Agency.

The Depocrete process is based on hydraulic binding agents that harden when water is added. The vendor claims that the hazardous materials are permanently bound and encapsulated into this system.

All information was supplied by the vendor and has not been independently verified.

Technology Cost

The Depocrete process is estimated by the vendor to cost from $100 to $200 per metric ton.

Information Source

D16658Z, vendor literature

T0140

Capping — General

Abstract

Caps, also called surface barriers or cover systems, are commonly used components of a containment system. Capping is used to cover buried waste materials to control their contact with the surrounding environment. A cap can have one or more of the following functions:

- Minimize the percolation of water into underlying contaminated materials.
- Raise ground surface, thereby generating more appropriate slopes to control surface-water runoff.
- Control the release of gas generated by underlying contaminated materials.
- Prevent exposure of humans, animals, or plants to hazardous materials.

Caps can be temporary (interim) or final. An interim cap is installed to minimize the generation of leachate until a better remedy is selected. Caps are also used to cover waste masses too large for treatment, such as tailings piles at mining sites. Capping is considered to be a proven, rather than an innovative, technology. Caps have been used at municipal and hazardous waste landfills for many years.

The main limitations of capping are the need for long-term maintenance and uncertain design life. Any cap must be periodically inspected for settlement, ponding of liquids, erosion, cracking, and naturally occurring invasion by deep-rooted vegetation or burrowing animals. Typically, groundwater monitoring is also required. Also, suitable soil and other materials for barrier construction may be scarce in certain regions.

Technology Cost

In 1998, the U.S. Environmental Protection Agency (EPA) stated that the cost of a cap (0.5 to 1 acre) can vary from $500,000 for a one-layer system to several million dollars for a multilayer cap. Costs are highly dependent on the local availability of soils suitable for construction and the requirements for monitoring, leachate collection, and gas collection (D188298, p. A18).

In 1995, it was estimated that cost of an asphalt barrier layer was approximately $96/m^2$, and the cost of installation of a high-density polyethylene (HDPE) barrier was estimated to be $7/m^2$ (D187331, p. 125).

In 1998, Delta Technologies and R.S. Means published cost data for capping technologies. Each layer of the cap is considered as a separate component of the total cost, as is the final daily cover, and operations and maintenance. Other cost considerations listed, but not summarized in this document are cleanup and landscaping, fencing and signage, clearing and grubbing, monitoring wells, storm sewer, decontamination facilities, and a retaining wall. Please refer to D189428 to review specific cost information.

Information Sources

D187331, Daniel and Gross, 1995

D189428, R.S. Means and Delta Technologies, 1998

D188298, U.S. EPA, 1998

T0141

Carbon Dioxide Pellet Surface Cleaning — General

Abstract

Solid carbon dioxide (dry ice) pellets can be used for the cleaning and decontamination of hazardous and radioactive materials from surfaces. The technology uses pressurized dry ice pellets that impact contamination materials and subsequently undergo sublimation (direct phase change from solid to gas). This serves to break the bond between the contaminants and the surface, lifting them off where they can be separated from the surface by the pressurized spray. The airborne contaminants are then removed by an air filtration system and the larger particles are collected in a treatment chamber. The technology is commercially available through several vendors for commercial cleaning and decontamination. Several automated and robotic systems are currently in development.

The advantages claimed for carbon dioxide pellet technology over other cleaning and decontamination technologies include lower process costs, no generation of secondary wastes, safer for employees, machinery, and the environment, reduced need for disassembly for cleaning, reduced risk of sediment or grit entrapment, better performance, adaptability for automation using robots, no electrical requirements, and the compact nature and portability of systems.

Carbon dioxide pellets can cause damage to sensitive surfaces. In a 1993 review of the technology, it was concluded the technology at its current level of development was too abrasive for sensitive semiconductor materials. Carbon dioxide pellet blasting has problems cleaning fixed contamination, as well as epoxy-coated concrete, carbon steel, rusted carbon steel, complex geometries, and the interior of pipes. In some applications of the technology, there have been hazardous buildups of carbon dioxide concentrations resulting in risk to personnel. For this reason, a large ventilation system was recommended for those uses of the technology.

Technology Cost

Full-scale equipment was estimated to cost between $250,000 and $300,000 in 1993 (D15088J, p. 6).

In a 1992 report for the U.S. Department of Energy (DOE) facility at Rocky Flats, it was estimated that the cost of operating the Alpheus carbon dioxide pellet system in a mixed waste removal application would be approximately $297 per hour. It was estimated that if the system was able to clean 100 lb of material per hour, the cost of cleaning a standard 5000 lb of material would be $14,850. This would be less than the cost of shipping the material for cleaning at another facility using conventional methods (D15087I, p. 4).

T0142

Carlo Environmental Technologies, Inc. (CET)

Medium-Temperature Thermal Desorption (MTTD)

Abstract
The medium-temperature thermal desorption (MTTD) system is a commercially available ex situ process that uses direct heat exchange to heat waste material in order to volatilize the organic contaminants. The process involves two steps: primary desorption and off-gas treatment. For desorption, contaminated soils are fed into a rotary kiln that heats the soil to a temperature that will volatilize the organic contaminants. The contaminants remaining in the off-gas from the kiln are destroyed by high-temperature oxidation before release to the atmosphere.

The Cedarapids soil remediation system (manufactured by Ratheon Company) used by Carlo Environmental Technologies, Inc., to treat contaminated soils by MTTD is similar to that used by another vendor. *See also* Advanced Environmental Services, Inc., System 64 MT Low-Temperature Thermal Desorption (T0009).

The Carlo MTTD equipment is portable and can be mobilized to the site. The system can treat soils from contaminant sources including underground storage tanks, refineries, pipeline leaks, terminals, and industrial properties. The MTTD technology can be used on most soil types, ranging from sand to silty clay, as well as speciality materials such as drilling muds and slags. It treats all types of hydrocarbons including solvents, gasoline, jet fuel, diesel oil, and up to No. 4 fuel oil. Following treatment, the soil may be placed back in the original excavation pit as clean compacted fill material.

Soils that are contaminated with chlorinated organics cannot be treated using the Carlo MTTD system since it is not equipped to treat acids that result in the off-gases.

The thermal desorption technology offered by Carlo Environmental has been in commercial use since 1990. As of 1995, four full-scale cleanup projects using the MTTD technology have been implemented.

Technology Cost
Cost estimate for the Carlo Environmental Technologies, Inc., MTTD technology range from \$30 to \$69 per ton of soil or other material treated. Factors that influence costs are characteristics of the soil (most important) utility and fuel rates, and moisture content of the soil. The initial and target contaminant concentrations also affect costs (D101871, p. 28).

Costs for four full-scale MTTD projects supplied by Carlo Environmental Technologies, Inc., are presented in VISITT 4.0. This information and site descriptions are shown in Table 1 (D101871).

TABLE 1 Cost of Treatment Using the Carlo Environmental Technologies, Inc., Medium Temperature Thermal Desorber

Site Location	Amount Treated	Cost per Unit[a]	Total Cost
Selfridge Air National Guard Base, MI	8,500 tons	\$32.00/ton	\$272,000
Grace United Methodist Church, MI	17,000 tons	\$34.68/ton	\$590,000
BASF, MI	8,341 tons	\$30.00/ton	\$252,930
Orlando International Airport, FL	58,995 yd^3	\$44.85/yd^3	\$2,645,925

Source: Information, supplied by the vendor is summarized from VISITT 4.0, 1995 (D101871).
[a]It is not known whether costs are estimated or actual.

T0143

Carson Environmental

Low-Temperature Oxidation

Abstract
The Carson Environmental (CE) technology is a mobile, ex situ technology for remediating particulate media or solid materials. The technology combines gas-phase oxidation agents or chemicals (ozone and hydrogen peroxide) and ultraviolet (UV) light in an on-site decontamination unit.

According to the technology developer, the technology treats excavated soils, sludges, and sediments contaminated with organic pollutants. The technology is applicable to media containing a wide range of particulate sizes, including clay with a particle diameter of 0.002 mm.

The developer asserts that the technology treats hydrogen contaminants containing 18 carbons or less (such as unleaded gasoline, kerosene, jet A, and jet B fuels). The technology also treats hydrocarbon derivatives, in addition to partially oxidized organic compounds such as alcohols, ketones, halogenated hydrocarbons, and a variety of pesticides (including those containing chlorine and phosphorous).

The technology has potential treatment applications in the following areas: agriculture, battery recycling/disposal, dry cleaning, herbicide manufacture or use, industrial landfills, inorganic/organic pigments, municipal landfills, paint/ink formulation, petroleum refining and reuse, plastics manufacturing, pulp and paper industry, and organic and inorganic chemical manufacturing.

According to the vendor, the technology has the following advantages: (1) the gas-phase hydroxyl radical is more reactive because of high reaction rate constants and (2) the technology is effective in the treatment of compounds that are resistant to aqueous-phase treatment by hydrogen peroxide, ozone, and UV light (especially hydrocarbon fuels, chlorinated pesticides, and aromatic compounds).

Technology Cost
No available information.

T0144

Carus Chemical Company

CAIROX Potassium Permanganate

Abstract
Carus Chemical Company offers CAIROX® potassium permanganate for the in situ remediation of volatile organic compounds (VOCs) in groundwater and soil. The method of oxidant delivery during treatment is tailored to site conditions. For unsaturated, low-permeability soils, CAIROX is introduced using deep soil mixing. In areas where the site has high permeability or the treatment media is saturated with water, well injection or recirculation can be used.

Potassium permanganate treatment methods are under development by the U.S. Department of Energy (DOE) and have been evaluated in field demonstrations. The technology is commercially available. CAIROX is a strong oxidant that has also been used commercially for many years in the chemical manufacturing, drinking water, and wastewater industries.

Researchers offer the following potential advantages of CAIROX potassium permanganate remediation technology:

- In situ treatment eliminates the need to dispose of secondary wastes.

- The reagent is cheap, easy to understand, and simple to use.
- Technology expected to treat contaminants more rapidly than other in situ technologies, leading to more rapid site closure and reduction in liability.
- Monitoring of the site is simplified.

While potassium permanganate will readily and completely oxidize chlorinated alkenes (e.g., trichloroethylene), chlorinated solvents having only single carbon bonds (e.g., trichloroethane) are not readily oxidized and may not be treated by this technology. Heterogeneities or low-permeability zones in the subsurface may cause uneven oxidant flow, increase treatment time, and produce tailing. The buildup of carbon dioxide formed during treatment may reduce the relative permeability of the sediment relative to water. Manganese dioxide and other forms of manganese will form coatings on soil grains during treatment and may result in the reduction of soil permeability over time. CAIROX should not be used at sites where oxidation could increase the mobility or toxicity of the co-contaminants. Potassium permanganate will react with the organic material in soils. Process residuals have not been fully characterized.

Technology Cost

In 1998, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) evaluated the use of potassium permanganate for the in situ oxidation of trichloroethene (TCE) at a CRREL facility. After this pilot-scale evaluation, researchers estimated that treatment costs for a field-scale application of the technology would range from \$20 to \$30/m^3 of soil treated, assuming a 2-year treatment period. Researchers stated that these costs were comparable to in situ bioremediation and cheaper than soil vapor extraction or stream flooding (estimated to be \$100/m^3 and \$120/m^3, respectively) (D18055M, p. 10).

An in situ chemical oxidation field demonstration using potassium permanganate for the remediation of chlorinated solvents was conducted in 1996 at the U.S. Department of Energy's (DOE's) Kansas City Plant in Kansas City, Missouri. The total cost of the demonstration was approximately \$1,000,000. This included all pre- and posttesting, permitting, equipment, and labor. The estimated cost of this technology is around \$128/yd^3 (D18766A, p.15).

In situ chemical oxidation using potassium permanganate was also demonstrated to treat dense, non-aqueous-phase liquid (DNAPL) at the Canadian Forces Base Borden in Ontario, Canada, between 1996 and 1997. This application used a series of six injection and five oxidant recovery wells. The total cost of the project was approximately \$45,000 (D18766A, p.13).

At the U.S. Department of Defense's (DOD's) Cape Canaveral Air Station in Florida, 68,200 kg of potassium permanganate were injected into the subsurface to treat TCE contamination. The overall cost of this demonstration was \$1,010,764. The overall costs included planning, permits, reports, mobilization, deployment, performance, monitoring, and project management (D22096C, pp. 1, 2).

In northern Ohio, 110 lb of dry potassium permanganate was used to remediate sandy soils contaminated with dichloroethene (DCE). The project required less than 1 week of on-site activities and cost less than \$10,000 (D22102T, p. 4).

The total cost of a field demonstration using CAIROX and an in situ chemical oxidation through recirculation (ISCOR) system at the DOE's Portsmouth Gaseous Diffusion Plant in Piketown, Ohio, was \$562,000. These costs do not include well construction. The demonstration was conducted using existing horizontal wells. The ISCOR system was used to treat contaminated soil and groundwater (D18766A, p. 17). Table 1 shows the breakdown of project costs. Unit costs for the ISCOR demonstration were \$101/yd^3 of soil treated (D20940F, p. 19).

The DOE used the above site date to produce a cost estimate of ISCOR technology. The estimate was prepared for the treatment of a DOE site with the associated departmental contractor rates, which are generally higher than contractor rates at industrial sites. Estimates involve three trichloroethylene (TCE) mass scenarios (8000, 16,000, and 25,000 lb of TCE to be treated). In each case, it was assumed that ISCOR treatment would only be used to treat the zone of highest contamination (hot spot treatment) (D20940F, pp. 17–18).

TABLE 1 Total Costs for the ISCOR Demonstration at the U.S. DOE Portsmouth Gaseous Diffusion Plant in Piketown, Ohio

Item	Cost
Project planning and management	$56,000
Pretreatment sampling and mobilization	$163,000
Operations and maintenance	$163,000
Posttreatment sampling	$101,000
Resistivity monitoring	$68,000
Support	$11,000
Total costs	$562,000

Source: Adapted from D18766A.

For the three DOE scenarios, treatment cost are estimated to be:

- Treatment of a 8000-lb TCE mass would be $778/lb.
- Treatment of a 16,000-lb TCE mass would be $451/lb.
- Treatment of a 25,000-lb TCE mass would be $363/lb (D20940F, p. 19).

According to DOE research, contaminant depth will be a significant factor in overall project costs. This is due to the costs of installing horizontal or vertical wells. Other contributing factors to ISCOR costs include duration of treatment and the volume/mass of contaminants requiring treatment (D20940F, p. 16).

In June 2001, the Interstate Technology Regulatory Cooperation (ITRC) work group published technical and regulatory guidelines for in situ chemical oxidation of contaminated soil and groundwater. The guidance document contains information that can be used in preparing cost estimates for chemical oxidation technologies. For more information, please see D22442A, Appendix D.

Although many of the costs for chemical oxidation technologies will be site specific, chemical costs will generally average 15 to 30% of the total remediation costs. Factors that influence chemical costs will include the chemical oxygen demand (COD) of the contaminated media, pH, the size of the site, and initial contaminant concentrations (D22442A, pp. 19, D-1).

Information Sources

D18055M, LaChance, 1998

D18766A, U.S. EPA, 1998

D22096C, Grattan, 2001

D22102T, SECOR International, Inc., 2001

D22442A, Interstate Technology and Regulatory Cooperation Work Group, 2001

D20940F, U.S. DOE, 1999

T0145

Caswan Environmental Services, Ltd.

Thermal Distillation and Recovery

Abstract

Caswan Environmental Services, Ltd. (Caswan) has developed the thermal distillation and recovery (TDR) process for the treatment of soil and sludge contaminated with organic hazardous

wastes. The system uses a three-step process, the first stage involving thermal desorption using nitrogen as a purge gas, the second stage uses an indirect-fired rotary kiln to remove any remaining organic contaminants, and the third stage is a vapor recovery system that condenses and recovers contaminants. The technology was commercially available and had been used for a full-scale cleanup in 1995. RIMS was unable to contact the vendor.

The vendor claims that the TDR process can be used to treat soil and sludge contaminated with polychlorinated biphenyls, polynuclear aromatic compounds, solvents, dioxins, furans, organic pesticides and herbicides, solvents, petroleum wastes, as well as nonhalogenated volatile and semivolatile compounds. The treated residuals from the process include recovered water, oil that can be used for recycling as an alternative fuel or for recycling or can be disposed, and clean soil that can be used as backfill. The volume of treated sludge is reduced by as much as 95% by this thermal process, depending on the initial level of contaminants.

Performance of the system is not limited by inorganic waste content of the soil, but the process does not remediate inorganic wastes. Desorption efficiency is affected by the composition of the contaminated soil (i.e., clay content). Moisture content and organic waste concentrations affect treatment efficiency and treatment rate.

Technology Cost

In 1995, Caswan estimated that treating contaminated soil using its thermal distillation and recovery technology would cost between $75 and $300 per ton. This estimate stated that price estimates may not include all indirect costs associated with treatment, such as excavation, permits, and treatment of residuals. Factors listed as having a significant effect on costs include (in decreasing order of importance) the characteristics of the soil, the moisture content of the soil, the initial contaminant concentration, quantity of waste, the target contaminant concentration, site preparation costs, waste handling and preprocessing costs, utility/fuel rates, labor rates, the characteristics of the residual wastes, the amount of debris associated with the waste, depth of the contamination, and the depth to groundwater (D10185Z, p. 23).

Information Source

D10185Z, VISITT, 4.0, 1995

T0146

Catalytic Combustion Corporation

SRCO and HD-SRCO

Abstract

The SRCO catalytic combustion unit treats volatile organic compound (VOC) laden process exhaust air. "SRCO" stands for self-recuperative catalytic oxidizer. The SRCO can be furnished as a complete operating vacuum extraction and catalytic oxidation system or as a stand-alone catalytic oxidizer to interface with an existing vacuum extraction and/or air stripper system. "HD-SRCO" stands for halogenated destruction self-recuperative catalytic oxidizer. This system is basically the same as the SRCO system, except that it remediates halogenated hydrocarbons using a different catalyst.

This technology is currently commercially available.

Catalyst exposure to the following substances must be avoided:

- Coating agents such as rust, dirt, and inorganic oxide
- Coating agents that are "glass" forming materials such as organic silicates (esters), silicones, and phosphorus containing materials

- Poisons such as mercury, lead, zinc, tin, arsenic, and antimony
- Sulfides, halogens, and organic droplets and aerosols

Technology Cost
According to the vendor, cost for this technology is site specific, being highly dependent on type and concentration of contaminants and required cleanup levels (personal communication: John Strey, Catalytic Combustion Corporation, 1996).

T0147

Catalytic Oxidation of Process Off-Gases — General

Abstract
Catalytic oxidation is used as part of a treatment train to remediate off-gas waste streams containing organic and some inorganic contaminants. This technology may be directly applied to off-gas wastes streams and, with an extraction pretreatment step, can be applied to water, soil, solid, and sludge. The technology treats organics such as polychlorinated biphenyls (PCB), pentachlorophenol (PCP), pesticides and herbicides, dioxins, and some inorganics, including cyanides.

Catalytic oxidation is capable of treating contaminant concentrations ranging from 1 part per million (ppm) to 20,000 ppm. Typically, it is applied to streams containing about 3000 ppm per volume or less of volatile organic compounds (VOCs). At levels approaching 3000 ppm per volume VOCs, the recoverable heat from the process may be sufficient to sustain oxidation without additional fuel.

Advantages of catalytic oxidation include the following:

- Destroys contaminants on site.
- Provides for thermal destruction of contaminants at relatively low temperatures (600 to 1000°F).
- Treats many dilute VOC-contaminated air emissions.
- Reduces potential for nitrogen oxides (NO_X) emissions when compared to incineration.
- Costs less than incineration or carbon adsorption in many applications.

Limitations of the technology include the following:

- Treatment of chlorinated VOCs will result in the generation of hydrogen chloride that may require further treatment.
- It is limited to the treatment of relatively dilute contaminated airstreams to prevent overheating of catalyst.
- Destruction efficiencies may be lower than other technologies due to lower temperatures.
- Spent catalyst must be replaced.

Technology Cost
Primary factors affecting the overall cost of catalytic oxidation include:

- Quantity of contaminants to be treated
- Type of contaminant (as it affect catalyst selection and off-gas treatment requirements)
- Required destruction efficiencies
- Concentration of contaminants
- Management of residuals
- Utility and fuel costs

Costs for catalytic oxidation systems are often included as a part of the entire remedial activity. Typical operating costs for a catalytic oxidation system alone, operating at 100 to 200 standard cubic feet per minute (scfm), will range from $8 to $15 per day (for natural gas or propane-fired systems) to $20 to $40 per day (for electrically heated systems). Capital costs of equipment operating at throughputs of 100 to 200 scfm are estimated to be in a range from $50,000 to $100,000 (D16641Q, p. 7).

Additional costs may include $10,000 to $50,000 for laboratory treatability studies and $100,000 to $500,000 for pilot tests or field demonstrations (D16641Q, p. 7).

The capital and operating cost comparisons of catalytic oxidation and carbon adsorption were conducted in 1991. For treating 5000 to 50,000 lb of total VOCs, the capital and operating costs of a 200-scfm, gas-fired catalytic oxidation system ranged from about $110,000 to $150,000. Over the same range, capital and operating costs of activated carbon with off-site regeneration range from about $80,000 to $550,000 (D16641Q, p. 7).

Several catalytic oxidation technologies are summarized in the RIMS library/database. They include Huntington Environmental Systems, Econ-Abator® Catalytic Oxidation System (T0383); Catalytic Combustion Corporation, SRCO and HD-SRCO (T0146); Global Technologies, Chloro-Cat Catalytic Oxidizer (T0350); On-Site Technologies, Modular Interchangeable Treatment System (MITS) (T0577); King Buck Technologies, Inc., HD CatOx System (T0459); NEPCCO, Photocatalytic Oxidation Technology (T0552); Alzeta Corporation, EDGE Thermal Processing Units (T0032). Please refer to the individual technologies for technology-specific cost data.

Information Source

D16641Q, NEESA, 1993

T0148

CBA Environmental Services, Inc.

Mobile Injection Treatment Unit (MITU)

Abstract

The mobile injection treatment unit (MITU) is a self-propelled, tracked, trenching machine custom-built from modified heavy equipment. It is designed to simultaneously excavate, treat, and backfill contaminated media in situ. The technology can also be used ex situ within a staging area. As the MITU excavates, it injects hot air, steam, or other materials into the soil for treatment. According to the vendor, MITUs are capable of treating a variety of contaminants including chlorinated solvents, aromatic/aliphatic hydrocarbons, halogenated volatiles and semivolatiles, pesticides and herbicides, dioxins and furans, polychlorinated biphenyls (PCBs), solvents, organic and inorganic cyanides, organic acids, heavy metals, asbestos, explosives and propellants, and possibly radionuclides. The MITU is a patented technology that has been used in more than 30 applications.

MITU is capable of treating soils, sludges, sediments, or slurries to depths of up to 30 ft, even through very dense soil, concrete, or rock. They are mobile systems that can be transported and set up quickly and easily. Three different MITU models are available, and each is designed for a different site type, size, and/or treatment rate application. The MITU can also be used for trench installation, slurry wall construction, or horizontal well installation.

MITU units cannot operate at depths greater than 30 ft below ground surface (bgs). Limited access and underground utilities at a site may also create problems for the use of this technology. In addition, depth of groundwater may be a limiting factor for some applications.

TABLE 1 Vendor-Supplied Site and Cost Data for the Mobile Injection Treatment Unit (MITU)

Location	Media	Contaminants	Bid Cost
DANA Corporation Chrome Plating Facility, Hagerstown, Indiana	9400 tons of soil	Hexavalent chromium	$750,000
Former Motorola Facility, Arcade, New York	4500 yd^3 of soil	Trichloroethene (TCE), toluene, ethylbenzene, and xylene	$500,000
Electro-Coatings Facility, Milwaukee, Wisconsin	14,400 tons of soil	TCE and tetrachloroethene (PCE)	$1,850,000

Source: D224099.

Technology Cost

According to the vendor, MITUs can be half the cost of alternative technologies such as incineration, landfilling, or soil vapor extraction (SVE) (D17269U, p. 8). At a petroleum and gas distribution site in Schuylkill Haven, Pennsylvania, 4200 tons of contaminated soil were treated at a cost of $18.63/ton. (D17269U, p. 30). Additional vendor-supplied cost information is presented in Table 1.

Information Sources

D17269U, CBA Environmental Services, Inc., 1997

D224099, CBA Environmental Service, Inc., Undated

T0149

Cement-Based Stabilization/Solidification — General

Abstract

Cement-based stabilization/solidification (S/S) is a technology for the in situ or ex situ treatment of hazardous wastes and hazardous waste sites. It is a process that uses cement and other additives or processes to physically and/or chemically immobilize the hazardous constituents of contaminated soils, sludges, sediments, or liquid wastes. The objective is to prevent the migration of contaminants in the environment by forming a solid mass.

By addition of certain chemicals reagents and rigorous mixing, the waste is fixed or stabilized. Contaminant mobility is reduced through the binding of contaminants within a solid matrix, which reduces permeability and the amount of surface area available for the release of toxic components.

These technologies do not remove hazardous wastes but rather attempt to immobilize them to prevent spreading.

The cement-based S/S technologies are best suited for the treatment of inorganic contaminants. Cement-based S/S is generally used for treating plating wastes containing metals such as cadmium, chromium, copper, lead, nickel, and zinc. It has also been used to complex wastes containing polychlorinated biphenyls (PCBs), oils, and oil sludges; wastes containing vinyl chloride and ethylene dichloride; resins; stabilized/solidified plastics, asbestos, arsenic, and other materials.

Technology Cost

The costs associated with S/S technologies have generally been considered low compared with those for other treatment techniques. The reasons for this are the availability of rather cheap raw products (e.g., fly ash, cements, lime), simple processing requirements, and the use of readily available equipment from the concrete and related construction industries (D150141, p. 7.99).

The final costs are highly dependent upon site-specific conditions. Contributing factors to the final cost include the waste characteristics, including its physical form and chemical makeup; the amount of pretreatment required; transportation of raw materials to the site and treated materials from the site; and other random factors such as health and safety requirements and regulatory factors (D150141, p. 7.100).

Specific cost information may be found in the individual technology summaries.

Information Source

D150141, U.S. EPA, 1989

T0150

Cement-Lock® L.L.C.

Cement-Lock Technology

Abstract

Cement-Lock® technology is an ex situ thermo-chemical manufacturing process. The technology converts soils, sludges, solids, river sediments, and marine sediments contaminated with organic and inorganic hazardous wastes into high-quality cement. The process involves melting the contaminated media with limestone at high temperatures, which destroys organic contaminants and immobilizes heavy metals. After cooling, the melt is pulverized and blended into building cement.

According to the vendor, Cement-Lock technology has successfully removed polycyclic aromatic hydrocarbons (PAHs), PCBs, and tetrachlorodibenzo-1,4-dioxin (TCDD)/2,3,7,8-tetrachlorodibenzofuran (TCDF) from soils and sediments in bench-scale tests. Metal concentrations were also reduced below detection limits in bench-scale tests. These metals included arsenic, cadmium, chromium, lead, nickel, mercury, and silver.

The vendor also claims that the end product of the Cement-Lock process surpasses the Environmental Protection Agency (EPA) Toxicity Characteristic Leaching Procedure (TCLP). This feature provides an advantage over competing technologies that produce less stable end products. Cement-Lock does have limitations. In 1997, a cost–benefit analysis was conducted by the Energy Resources Center at the University of Illinois, Chicago, to assess the profitability of the technology. This study indicated that Cement-Lock would "have a low probability for success for processing clean concrete and asphalt wastes as well as low level, less than 50 ppm PCB, toxic waste."

Cement-Lock is being commercialized through a partnership between the Gas Research Institute, the Institute of Gas Technology, and Endesco Clean Harbors L.L.C.

Technology Cost

The vendor estimates the cost of Cement-Lock plant construction to be about $\$200/yd^3$ times its annual capacity. According to the vendor, a preliminary economic assessment of the Cement-Lock processing plant indicates a payback of capital within 2 years of operation (D16285Q, p. 5).

The cost of treatment using Cement-Lock technology was estimated to be \$30 to \$40 per ton in 1997, compared with \$450 and \$300 per ton for alternative disposal routes (D16285Q, p. 10).

The vendor further claims that the blended cement product can be sold for approximately $60 per ton (D18214J, p. 25).

Cement-Lock is being tested at the Port of New York/New Jersey as a low-cost alternative to ocean disposal of dredged sediments. At their lowest, costs of sediment dredging and ocean disposal can range from $6 to $12/m^3. According to Stern et al., unspecified "additional" costs can add another $35/m^3 to total disposal costs (D19312O, p. 71). Although no cost information for Cement-Lock is available from this site, the technology was chosen because its projected costs were less than the costs of ocean disposal (D19867I, pp. 1–2).

Information Sources

D16285Q, Cement-Lock L.L.C., date unknown

D16286R, Environtech, 1997

D18214J, Industrial Wastewater, 1997

D19312O, Stern et al., 1997

D19867I, Brookhaven National Lab, 1998

T0151

Ceramic Immobilization — General

Abstract

Several stabilization technologies immobilize radioactive materials by forming a synthetic ceramic material that mimics natural minerals. Ceramic immobilization technologies can involve low-temperature processes, such as the ceramification technology researched at the U.S. Department of Energy (DOE) Rocky Flats Facility, or high-temperature processes. High-temperature technologies include two technologies originally developed in Australia, the synthetic rock (SYNROC) process, and the synthetic mineral immobilization technology (SMITE). SMITE technology is commercially available in the United States and is discussed in the RIMS database (T0789). The SYNROC and ceramification technologies are not currently commercially available in the United States.

While each of the above technologies offers certain unique advantages, those common to ceramic immobilization include: a relative ease in fabrication, a high capacity for actinides or heavy metals compared to other technologies, the capacity for flexibility of feedstock, the ability to add neutron absorber materials for nuclear waste applications, and the ability to control the properties of the final waste form.

Although the ceramification and SYNROC technologies are being researched to develop a final waste form for plutonium-contaminated materials, no experiments with plutonium have been performed. The SMITE process is designed for the treatment of solid, inorganic materials. The final waste form will leach in acidic solutions; so storage in a basic environment is recommended.

Technology Cost

According to researchers, furnaces for ceramic immobilization processes typically cost less than $1000 (D16044B, p. 155). According to the researchers, the SYNROC approach is only cost effective for large-scale applications (a large-scale application is assumed to produce 30-cm-diameter disks, each weighing approximately 30 kg). Cold press applications of the SYNROC process are more cost effective (D160429, pp. 255–256). No cost information is available for the Ceramification and SMITE processes.

Information Sources

D160429, Ebbinghaus et al., undated

D16044B, Rask and Phillips, undated

T0152

CerOx Corporation, Incorporated

Mediated Electrochemical Oxidation

Abstract
Mediated electrochemical oxidation (MEO) is an ex situ treatment technology that uses electricity, acid, and a metal catalyst to destroy organic wastes at low temperatures and pressures. The proprietary CerOx Corporation MEO configuration uses cerium metal as a catalyst to oxidize organic waste into carbon dioxide and water. The process occurs in an acidic solution, typically nitric acid. The first step involves the generation of an oxidant at the anode, followed by the reduction of water or another chemical species at the cathode. This technology serves as a nonthermal alternative to incineration.

Over the past 20 years, The U.S. Department of Energy's (DOE's) Pacific Northwest National Laboratory (PNNL) has developed the patented MEO technology using cerium as a metal catalyst. CerOx Corporation holds as exclusive, world-wide license to market the proprietary, cerium-based MEO process. The first commercial CerOx system was sold to the University of Nevada in Reno. The technology is commercially available.

Advantages of CerOx MEO process include the following:

- Inexpensive to manufacture, service, and replace.
- Designed to handle virtually any volume of waste.
- Cost-effective due to elimination of handling and transport, decreased operating costs, and reduced capital costs.
- Closed-loop system, electrolyte is recycled, and metal is re-oxidized.
- Liability is limited because waste is treated at source.
- Organic molecules containing oxygen and chlorine are already partially oxidized and are therefore more easily destroyed.

Limitations of the CerOx MEO include the following:

- Waste must be in a liquid or slurry form that can be pumped.
- Treatment rate is waste specific.
- Oxidant is short lived and cannot be stored.
- Recovery and recycle of acid and metal is complicated.
- Process relies on the integrity of the membrane.
- Nitrous oxides produced at the cathode must be oxidized back into nitrate.

Technology Cost
According to the vendor, cerium-based MEO technology should be cheaper than incineration for certain applications (D11745D, p. 1). The technology is targeted for sale to small-quantity generators who currently pay an average of \$250 to \$500 to treat a 55-gal drum of waste. Treatment of the same quantity of waste would cost \$100 to \$250 using the MEO technology. Over the lifetime of the equipment, capital costs may exceed operating costs (D169522, p. 1; D222184, p. 11).

The vendor estimates that the costs of smaller CerOx MEO systems range from \$200,000 to \$4,800,000. The cost for one CerOx System 2 would range from \$300,000 to \$400,000. According to the vendor, the electricity and capital costs for a CerOx System 4 used to treat laboratory wastes would be approximately \$90,000 per year (D22213Z, p.; D22609F; D222184, p. 9).

Information Sources

D11745D, Pacific Northwest Laboratory, 1995
D169522, EOSystems, 1997
D22213Z, CerOx Corporation, undated
D222184, CerOx Corporation, 2000
D22609F, CerOx Corporation, 2001

T0153

Certified Remediation Systems, Inc.

CRS Process

Abstract
The CRS process is a commercially available closed-loop technology that is designed to separate hydrocarbon contaminants from soil without the use of surfactants or other additives. According to the vendor, this technology can be used to remediate petroleum production facilities, refineries, and other industrial sites including airports, military bases, tank farms, fuel storage and transportation terminals, and waste sites.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0154

CF Systems Corporation

Liquefied Gas Solvent Extraction

Abstract
Liquefied gas solvent extraction (solvent extraction) is an ex situ process developed by CF Systems Corporation (CF Systems) and CF Technologies, Inc., as a means to extract organic contaminants from soils, sludges, sediments, refinery wastes, and wastewater. The process works by liquefying a gas such as propane, under pressure, and using it as a solvent to extract contaminants from a waste stream. The resulting mixture of solvent and organics then passes from the extraction system to a separator where the organics and solvent are separated and the solvent is vaporized and recycled.

CF Systems' extraction process removes a broad range of contaminants and typically extracts more than 99% of the organic contaminants from the waste feed. However, the CF Systems process cannot remove heavy metals or other inorganics. Also, the CF Systems process does not destroy the organic contaminants in soil or waste but rather extracts them from the medium in which they are contained.

CF Systems has constructed several commercial-scale systems and has installed them at wastewater, industrial, and petroleum refinery sites. They currently only offer solvent extraction for food processing waste streams.

Technology Cost
In 1988, the CF Systems Pit Cleanup Unit (PCU) was demonstrated at the New Bedford Superfund Site in Massachusetts, under the Environmental Protection Agency's (EPA) Superfund

TABLE 1 Base-Case Cost Summary—New Bedford CF Systems

PCU SITE Demonstration	Process Costs (1989 U.S. dollars)
Facilities	5,170,676
Extraction	62,109,781
Pre/posttreatment	46,172,028
Contingency	11,345,248
Project management	5,672,624
Overall cost of remediation	130,470,358
Extraction only ($/ton)	71
Total cost per ton[a]	148

Source: Data adapted from Table 4-1, EPA Applications and Analysis Report, page 26.
[a] Total cost per ton represents the average cost over an 8-year operation period.

Innovative Technology Evaluation (SITE) demonstration program. Based on information from the demonstration, an economic analysis was performed to estimate costs associated with a commercial-size unit using the technology. CF Systems developed criteria and costs for a base case and a hot spot case and then extrapolated these costs to three other cases (D132627, p. 21).

The base case hypothesizes the treatment of 880,000 tons of sediments containing 580 parts per million (ppm) of polychlorinated biphenyls (PCBs). The estimates in Table 1 represent the base-case scenario developed during the demonstration (D132627, pp. 21–29; pp. 52–54).

For more system design, cost information and vendor estimates concerning this SITE demonstration, see the EPA Applications Analysis Report, pages 21 to 29 and pages 52 to 54.

According to the vendor, the unit cost of the remediation at the United Creosote site in Conroe, Texas, was $220 per ton (D20539A, p. 4–22).

In 1997, CF Systems provided a general solvent extraction price range of $75 to $400 per ton of contaminated material. The quantity of waste requiring remediation, the characteristics of the soil, the target contaminant concentrations, and the initial contaminant concentrations would most strongly affect the unit treatment price of the process (D20539A, p. 4–22, 4–24).

Information Sources

D132627, U.S. EPA Applications and Analysis Report, 1990

D20539A, U.S. EPA, 1997

T0155

CFX Corporation

CFX MiniFix

Abstract

The CFX MiniFix™ technology is categorized as a chemical fixation/stabilization process. The patented process, enhanced by additional proprietary developments, stabilizes mobile constituents within a waste matrix by utilizing the chemical reactions between complex silicates. The reactions solidify and stabilize the wastes into a claylike product that is suitable for either on-site or landfill disposal. The matrix-forming chemistry is assisted as needed by reaction-promoting additives.

The CFX MiniFix technology can treat solids, sludges, and most liquids. The treatment is applicable to a variety of heavy metals such as aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, hexavalent chromium, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, and zinc. The technology also treats organic compounds with high molecular weights.

The developer claims that the technology is applicable in the following industries: automotive, chemical, metal finishing, municipal, petrochemical, primary metals, pollution control, power, and resource exploration. According to the developer, the process is primarily used in industries that generate the following types of wastes: spent soil and gas drilling fluids, contaminated soils, nonhazardous industrial waste, municipal wastewater sludges, and certain types of industrial hazardous wastes.

According to the technology developer, the CFX MiniFix technology has the following advantages:

- Blends all waste to the same standards.
- Produces a synthetic soil (stabilized waste with soil-like qualities) that has greater erosion resistance than natural soil, enhanced slope stability, and has a greater affinity for soluble heavy metals.
- Is a self-contained, closed-loop system that produces no secondary discharges or air emissions.
- Limits waste volume increase to a range of 5 to 15 %.
- Eliminates costs associated with hazardous waste storage, treatment, and disposal; the hazardous waste is either reclassified or deregulated as nonhazardous.

Technology Cost

According to the technology developer, the CFX MiniFix technology costs approximately $40 to $100 per ton of raw waste processed (D14187H, p. 8). The unit used in an international feasibility study/unit demonstration (in which it was shipped from Kenner, Louisiana, to Budapest and Fuzfogyartelep, Hungary, and then to Montreal and Ottawa, Canada) cost $225 per day to operate (D151100, p. 8).

The developer claims that miscellaneous operating, utility, and maintenance expenses will add costs of approximately $0.25 to $1.00 per ton of waste treated (D151100, p. 7).

The developer notes that mobilization and demobilization costs are affected by both the location of the site and the type and quantity of waste. Mobilization and demobilization costs range from $300 to $10,500 for most global destinations (D151100, p. 7).

According to the developer, the amount of moisture in the material to be treated also affects the cost. Wastes containing less than 20 to 30% moisture are more expensive to treat than liquid wastes. A reasonable range of reagent costs will be within approximately $25 to $35 per feed ton (D151100, p. 7).

In general, the cost for CFX stabilization treatment is affected by several factors (D14187H, p. 8):

- Contaminant type
- Amount of contamination
- Waste volume
- Location and accessibility of waste

Information Sources

D151100
D14187H, P.N. Baldwin, Jr. and W.A. Brown, October 2–4, 1991

T0156

CH2M Hill and Reichhold, Inc.

Jet Pump Recovery System

Abstract
CH2M Hill and Reichhold, Inc., have developed the jet pump recovery system for the recovery of fluids and vapors from contaminated soil and groundwater. The technology uses eductors similar to those used in jet engines. An eductor can be defined as an ejector-like device for the mixing of fluids. The system works by pumping pressurized fluid through nozzles in the eductors, creating a vacuum on the suction side of the device. Fluid or vapors are then drawn from the recovery wells into the suction side of the eductor. The recovered fluid or vapor is entrained by the pressurized fluid and the mixture is discharged through the jet pump system to discharge piping.

The vendors state that since 1995, the technology has been evaluated using two different full-scale configurations and has been used to recover petroleum hydrocarbons at several leaking underground storage tank sites and refinery facilities in the midwestern United States. The vendors have applied for patents on the technology. The technology is commercially available.

The vendors state that the jet pump system has the following advantages:

- Low-cost installation and use.
- Operates without damage if wells go dry.
- Allows for one-pass or circulating jet modes of use.
- Operates at deep or shallow levels.
- Several recovery wells can be operated from one drive unit.

All information in this summary is from the vendors and has not been independently verified.

Technology Cost
No available information.

T0157

CH2M Hill

Waterflood Oil Recovery

Abstract
Waterflood oil recovery is a commercially available, in situ technology for the treatment of groundwater contaminated with dense non-aqueous-phase liquids (DNAPLs) such as oil. Waterflood oil recovery is tailored to specific site conditions and is generally used in conjunction with barrier technologies. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0158

CH2M Hill

Phytoremediation-Based Systems

Abstract

Phytoremediation is the use of plants to treat or stabilize contaminated soils, sediments, or water. Plants provide and support remediation processes in many ways. Common applications of phytoremediation-based systems include remediation of contaminated soil and groundwater, reuse of municipal wastewater and biosolids, reuse of industrial wastewater and by-products, alternative landfill capping and erosion control, and landfill leachate reuse.

Since 1989, CH2M Hill has permitted, designed, researched, installed, managed, and monitored approximately 30 treatment and remediation projects using poplar trees. CH2M Hill integrates both plant-based and engineering aspects of a project to provide site-specific phytoremediation-based systems.

The vendor states that phytoremediation systems offer the following advantages:

- Less expensive than conventional remediation methods.
- Accelerates natural breakdown of contaminants.
- Can halt off-site migration of pollutants.
- Indirectly improves nearby water quality through nutrient and contaminant uptake.
- May be used for riparian or other habitat restoration.
- Enhances educational and recreational activities within the community.
- Improves site aesthetics.

Plants are living organisms with physical requirements that are often in conflict with the nature of the pollutant or the industrial setting to be remediated. These requirements can include soil pH, soil texture, and available nutrients. Hybrid poplars are reasonably tolerant of organic compounds, but high concentrations of metals, salts, and ammonia are toxic. Phytoremediation is also a slower process than alternative technologies, and cleanup often requires several growing seasons.

Technology Cost

The Oregon Department of Environmental Quality (DEQ) in conjunction with CH2M Hill designed a phytoremediation database that lists cost information for phytoremediation projects in Oregon. Estimated costs for the 14.3-acre Ecolotree Cap used at Riverbend Landfill in McMinville, Oregon, were $45,000 for tree planting, $35,000 to $80,000 for monitoring, and $28,000 for irrigation. This application was slightly different than other landfill caps in that landfill leachate is applied directly to the poplars for remediation (D198156, p. 13).

At an Oregon landfill, costs for installing an Ecolotree cap were $10,000 per acre, and cost savings for the installation alone were approximately $90,000 per acre (D197437, p. 1).

An Oregon wastewater treatment plant (WWTP) estimates the capital cost for development of the initial 80 acres of a 320-acre site as $4,610,200, plus additional operational and maintenance costs of $120,900 per year. Operational and maintenance costs depend on the amount of land under development, harvesting, and replanting activities (D197131, p. 7-2). It is assumed that the poplar trees at the site will provide a source of revenue from the sale of wood chips. Revenue from the chips is estimated at $80 per bone dry ton (BDT), with an annual increase in worth of 4%. The first harvest is scheduled for 2006. Revenue from harvesting efforts will help offset a portion of the capital, operational, and maintenance costs of the system (D197120, p. 29).

CH2M Hill installed a complex irrigation and subsurface drainage system for highly saline metallurgic processing effluent at OREMET Titanium in Albany, Oregon. The cost of the study was $40,000, while design/build costs were $250,000. Yearly operations and management costs for the system, which range from $20,000 to $100,000, are high because of vigorous site monitoring required by the state (D198156, p. 13).

The costs of installing a phytoremediation-based system at the Mill Creek Correctional Facility in Salem, Oregon, were $260,000. The facility paid $10,000, and the rest was paid through donations (D198156, p. 13).

Because phytoremediation utilizes solar energy, the technology requires few energy inputs. This factor reduces operating costs. In addition, expenses are spread out over a greater time period than other technologies since phytoremediation is a slower treatment process. The result is lower annual costs. Frick et al. also note that "agronomic costs, including planting, tillage, fertilization, and harvesting, can be insignificant in comparison with associated administrative costs, such as site management, regulatory reporting, and analysis of data" (D20756H, pp. 42, 43).

Information Sources

D198156, Oregon DEQ, 1999
D197437, EcoToday, 1999
D197120, CH2M Hill, 1998
D197131, CH2M Hill, 1998
D20756H, Frick et al., 1999

T0159

Charbon Consultants

HCZyme

Abstract
HCZyme is a commercially available aqueous biostimulation agent composed of bacterial growth enhancing agents, extracellular enzymes, and surfactants. HCZyme is designed to enhance the in situ bioremediation of numerous petroleum-based contaminants in soil and water by stimulating indigenous microbes to degrade them. Specifically, HCZyme produces the following results:

- Increases the number of petroleum-degrading microbes.
- Provides extracellular enzymes that initiate the breakdown of petroleum hydrocarbons, enhancing bioremediation.
- Maintains the microbial population so even low concentrations of contaminant can be treated.
- Contains surfactants to desorb petroleum from soil particles and to assist in moving petroleum and nutrients through the soil more easily.

HCZyme has been demonstrated in bench-scale tests and at field remediations to be effective on benzene, toluene, ethylene, and xylene (BTEX), Polycyclic aromatic hydrocarbons (PAHs), trichloroethylene (TCE), dichloroethylene (DCE), mineral spirits, fuel oils, motor oils, and hydraulic fluids. The vendor claims that HCZyme has been tested and used on over 2 million tons of petroleum-contaminated soils and is effective in breaking down petroleum hydrocarbons, polychlorinated biphenyls (PCBs), creosote, sludges, waste oils, free product, tank bottoms, and other chlorinated compounds (D18208L, p. 15).

The major limitations of this technology are those factors that affect bacterial growth, including temperature, pH, and presence of other contaminants detrimental to bacteria life. Other factors

that may affect speed and completion of contaminant breakdown include moisture level, soil properties, and microbe mobility.

Technology Cost

One gallon of the HCZyme concentrate will clean about 8 yd^3 of contaminated media, and cost \$55 in 1997, or approximately \$7/yd^3. This estimate does not include engineering and other associated costs such as excavation, permits, and treatment of residuals. According to the vendor, chemical costs are approximately \$7/yd^3, and total treatment costs range from approximately \$15 to \$50/yd^3 (D15846X, pp. 6, 9; D18211G, p. 1).

Information Sources

D15846X, Charbon Consultants, date unknown

D18211G, Remtech Engineers, 1997

T0160

Chemfix Technologies, Inc.

Chemfix Solidification/Stabilization Technology

Abstract

The Chemfix™ process is categorized as a chemical fixation/stabilization technology. This patented process, enhanced with proprietary developments, stabilizes mobile constituents within a waste matrix by chemical and physical means.

Chemfix designed the process to reduce the mobility and toxicity of metals and base, neutral, and acid (BNA) extractable organics with high molecular weights. The Chemfix solidification/stabilization technology can treat solids, liquids, and sludges ranging between 8 and 75% solids by weight. The technology is also suitable for contaminated soils, ashes, and other solid wastes. The Chemfix technology has been applied to industrial wastes, spiked electroplating waste, wastes from Superfund sites, and municipal waste.

The innovative features of the system include proprietary reagents, the pug mill designed by Chemfix, and the continuous nature of the process. Because it is a continuous process, waste material can be treated more quickly, thus lowering the cost per ton of material treated.

The amphoteric nature of lead should be considered when using the Chemfix technology. The potentially high alkalinity of solidified/stabilized waste material suggests that, at very high concentrations (pH >11), lead may leach from a solid matrix. The potential for lead leaching increases if metal hydroxides are formed, and the material is disposed of in an area with leachate or groundwater that is neutral or alkaline. Chemfix claims, however, that metal silicates rather than metal hydroxides are formed, thereby eliminating the potential problem of increased solubility at high pH (>11).

One disadvantage associated with the Chemfix technology is a waste volume increase. After the Chemfix process solidifies/stabilizes wastes, the volume of wastes increases, resulting in a larger volume of material requiring disposal than the original volume. Chemfix claims, however, that the normal volumetric increase has been less than 20% for approximately 95% of wastes treated.

Technology Cost

In 1997, the vendor stated that Chemfix technology costs range from \$30 to \$50 per ton of raw waste treated (personal communication, D. Donaldson, Chemfix Technologies, Inc., 9/97). In 1991, the treatment cost of the Chemfix technology was estimated to range from \$40 to \$80 per ton of raw waste treated. This cost information is based on information supplied by Chemfix,

TABLE 1 Estimated Costs of Chemfix Treatment Technology by Category

Fixed-Cost Category	Estimated Costs (1990 $)[a]	
Site preparation	$50,000	
Permitting and regulatory	$25,000	
Equipment installation and startup	$8,500	
Trailer transport to site	$12,500	
Mobilization/demobilization	$12,000	
Equipment repair and replacement	NA	
Effluent treatment and decontamination	$2,500	
Total fixed costs	$110,500	
Total fixed cost per ton	$3	
Variable-Cost Category	**Cost per Ton of Waste Treated**	
Source	(D130847,p. 13)[a]	Vendor[b]
Capital equipment rent/lease	$5	$5
Labor	$27	$5
Chemfix reagents	$30	$15
Utility and miscellaneous	$3	$2
Analytical	$5	$3
Total variable cost per ton	$70	$30
Total treatment cost per ton of raw waste	$73	$33

[a] Adapted from (D130847, p. 13) based upon 30,000 yd^3 (24,000 m^3) processed at 160 tons per day.
[b] Values provided through personal communication with D. Donaldson, Chemfix Technologies, Inc., 9/30/97.

and on materials-handling costs experienced during the U.S. Environmental Protection Agency (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration at the Portable Equipment Salvage Company (PESC) site in Clackamas, Oregon. The cost does not include site preparation costs, equipment transport costs, and disposal costs. The cost of the technology depends heavily on the processing rate (D104494, p. 1).

Table 1 contains estimated costs (by category) using the Chemfix treatment technology. The cost figures are extrapolated treatment costs, based on 37,000 tons of soil processed at 160 tons per day at the PESC SITE demonstration (D130847, p. 13).

The cost-effectiveness of the Chemfix process depends partly on whether treated material may be disposed of as nonhazardous waste. If waste remains hazardous after treatment, it must be disposed of as a hazardous waste at a specified facility; this causes a significant increase in the total cost of Chemfix treatment (D130847, p. 9).

Information Sources

D104494, U.S. EPA Technology Demonstration Summary

D130847, U.S. EPA Applications Analysis Report, May 1991

T0161

Chemical Oxidation — General

Abstract

Chemical oxidation is a process in which the oxidation state of a contaminant is increased while the oxidation state of the reactant is lowered. The reactant can be another element, including an

oxygen molecule, or it may be a chemical species containing oxygen, such as hydrogen peroxide or chlorine dioxide.

Because it is a nonselective treatment, chemical oxidation is best suited for media with low concentrations of contaminants. This technology has been demonstrated to be effective in treating wastes contaminated with halogenated and nonhalogenated volatile and semivolatile compounds, polychlorinated biphenyls (PCBs), pesticides, cyanides, and volatile and nonvolatile metals.

Both in situ and ex situ chemical oxidation technologies are commercially available for the treatment of liquids, soils, and sludges containing hydrocarbons and other oxidizable contaminants.

Chemical oxidation advantages include:

- Proven effective at hundreds of sites in the United States.
- Destroys organic contaminants.
- Operates more quickly than other techniques (in months rather than years).
- Can be used in situ, reducing treatment costs.

Chemical oxidation limitations include:

- Less cost effective at sites with high contaminant concentrations.
- Reaction rates must be carefully controlled due to the energetic nature of the chemical oxidation.
- Compounds in the contaminated media can interfere with contaminant oxidation.

Technology Cost

In June 2001, the Interstate Technology Regulatory Cooperation (ITRC) Work Group published technical and regulatory guidelines for in situ chemical oxidation of contaminated soil and groundwater. The guidance document contains information that can be used in preparing cost estimates for chemical oxidation technologies. For more information, please see D22442A, Appendix D.

Although many of the costs for chemical oxidation technologies will be site specific, chemical costs will generally average 15 to 30% of the total remediation costs. Factors that influence chemical costs will include the chemical oxygen demand (COD) of the contaminated media, pH, the size of the site, and initial contaminant concentrations (D22442A, pp. 19, D-1). Cost data included in case studies provided by the ITRC are summarized in Table 1

Table 2 shows a set of costs derived from an application of Oxidation Systems, Inc.'s, HYDROX™ oxidation process for the treatment of extracted groundwater at a site in Ontario, Canada. The costs are based on a treatment rate of 30 gal/min, for 355 days of operation per year. The cost of electricity for this estimate is 5 cents/kWh, and 100% hydrogen peroxide costs 63 cents/lb (D15504E, p. 2).

In 1991, operating costs for mobile chemical oxidation systems ranged from \$70 to \$150 per 1000 gal of water treated. Operating costs for the Ultrox® enhanced system varied dramatically from \$0.15 to \$90 per 1000 gal treated, depending on the type and concentration of contaminants and the site cleanup goals. The greatest cost for the Ultrox system is the cost of electricity to operate the ozone generator and ultraviolet (UV) lamps (D123626, p. 7). A cost estimate prepared during a U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration of Ultrox technology is included in Table 3.

In a 1994 project funded by the U.S. Army, it was estimated that the remediation costs for granular activated carbon and ultraviolet chemical oxidation ranged from \$1.00 to \$5.00 per 1000 gal of contaminated groundwater treated. It was estimated that a peroxone system that uses a combination of hydrogen peroxide and ozone to generate hydroxyl radicals could potentially cost \$0.02 to \$0.10 per 1000 gal of groundwater treated (waste streams containing

TABLE 1 Cost Information for Various In Situ Chemical Oxidation Technologies

Site Name	Treatment Type	Individual Cost Items Listed	Total Cost
Dry cleaning site, Garden City, Kansas	Ozone	\$31,000—system components \$25,000—injection and monitoring well installation \$25,000—maintenance and repairs	\$81,000
Dry cleaning sites, Hutchinson, Kansas	Ozone	\$50,000—system components \$30,000—injection and monitoring well installation \$25,000—additional SVE[a] components \$17,000—controller installation \$11,000—operation, maintenance, and repairs	\$133,500
Dry cleaning sites, Wichita, Kansas	Sodium permanganate	\$4,500—monitoring well installation \$10,000—injection event materials and labor \$21,000—SVE installation \$14,000—pre- and postinjection sample collection and analysis	\$49,000
Gas station, Madison, Wisconsin	Fenton's reagent	Costs stated to include drilling, reagents, labor, and pilot testing	\$270,000

Source: Adapted from D22442A.
[a] SVE = soil vapor extraction.

TABLE 2 Estimated Costs to Operate the HYDROX Oxidation Process

	Cost per 1000 gal (\$)	Cost per Day (\$)	Cost per Month (\$)	Cost per Year (\$)
Electricity	0.22	9.58	284	3,400
Hydrogen peroxide (20 ppm)	0.08	3.24	96	1,151
Maintenance	0.25	10.68	320	3,845
Total	0.55	23.50	698	8,396

Source: D15504E, p. 2.

low concentrations of contaminants). This estimation was based on information from French engineers that have used the technology to treat drinking water on a commercial basis (D160269, p. 2).

An EPA study indicated that the groundwater remediation cost for a 50-gal/min, 5-kW Perox-Pure™ system would range from \$7 to \$11 per 1000 gal, depending on contaminated

TABLE 3 Estimated Costs (in 1990 Dollars) Associated with Three Ultrox System Units

	Type of System Used [Treatment Rates in Gallons per Minute (gpm)]		
Cost Item	20 gpm unit	100 gpm unit	250 gpm unit
Site preparation costs[a]	36,000	55,000	75,000
Permitting and regulatory costs[a]	3,500	7,500	13,000
Capital equipment costs[a]	70,000	150,000	260,000
Startup and fixed costs[a]	32,000	32,000	32,000
Labor costs[b]	6,600	6,600	6,600
Supply and consumables costs[b]	10,500	16,500	20,800
Utility costs[b]	12,000	58,000	145,000
Effluent monitoring and disposal costs[b]	3,000	3,000	3,000
Residuals and waste shipping, handling, and transporting costs[b]	1,000	5,000	7,000
Analytical costs[b]	24,000	24,000	24,000
Equipment repair and replacement[b]	4,000	22,000	33,000
Site demobilization costs[a]	2,000	3,000	4,000
Total one-time costs	143,500	247,000	384,000
Total operation and maintenance costs	61,100	135,100	239,400
Total cost	204,600	382,100	623,400
Total water treated in million gallons	10.5	52.5	131.5
Cost per 1000 gallons of water treated	\$19.49	\$7.28	\$4.74

Source: Adapted from D13629I.
[a] One-time costs.
[b] Annual operation and maintenance costs.

groundwater characteristics. Of this total cost, the Perox-Pure system direct treatment cost would range from \$3 to \$5 per 1000 gal. The EPA analysis was based on operation of the system for a period of 10 years to treat a total of 26 million gallons of contaminated groundwater (D10057S, pp. 21–27).

Information Sources

D123626, U.S. EPA, October 1995

D160269 Envirosense web page, 1994

D15504E, Oxidation Systems, Inc., date unknown

D22442A, Interstate Technology and Regulatory Cooperation Work Group, 2001

T0162

Chemical Precipitation of Metals — General

Abstract

Chemical precipitation of metals from groundwater is an ex situ technology that involves the conversion of soluble heavy-metal salts to insoluble salts that will precipitate. The precipitate

is removed from the treated water by physical methods such as clarification (settling) and/or filtration. The precipitation process must be coupled with a solids removal process, otherwise, metal precipitate solids may carry over into the effluent and negatively affect effluent quality and process efficiency.

This technology involves the addition of chemical reagents to cause insoluble compounds to form. A common method used to precipitate metal ions is pH adjustment. The desired pH is one in which the metals exhibit low solubilities in water and therefore precipitate. Common reagents used for pH adjustment include alkalis such as lime, caustic soda, or magnesium hydroxide slurries to precipitate metal hydroxides. Sulfides such as sodium sulfide or ferrous sulfide slurries are often used to precipitate metal sulfides. Other reagents, such as xanthates, can also be used to precipitate metal ions.

Chemical precipitation is applicable to most heavy metals likely to be found in contaminated groundwater. Examples of metals that have been removed to a concentration of less than 1 ppm include cadmium, chromium, nickel, zinc, manganese, copper, tin, iron, arsenic, lead, and mercury. Chemical precipitation is widely used to meet National Pollution Discharge Elimination System (NPDES) requirements for the treatment of heavy-metal-containing wastewaters. In many cases, metals precipitation may also be used as a pretreatment step prior to discharge of the wastewater to a publicly owned treatment works (POTW).

Disadvantages of the technology include the following factors:

- If the source of contamination is not removed, treatment of the groundwater may be ineffective as a long-term solution.
- Reagent addition must be carefully controlled to preclude unacceptable concentrations in treatment effluent.
- Efficacy of the system relies on adequate solids separation techniques.
- Process may generate toxic sludge requiring disposal.
- Dissolved salts are added to the groundwater as a result of pH adjustments.

Metal precipitation and removal may also be used as a pretreatment step prior to a subsequent treatment for removal of other contaminants. Examples of their downstream process include ultraviolet oxidation, air stripping, and biological treatment (D16512I, p. 5–6).

Technology Cost

Capital and operating costs vary greatly over the wide range of precipitation systems in use. The primary factor affecting capital costs is design flow rate, while the primary factor affecting operating cost is labor. For two similar packaged metals precipitation systems one operating at 20 gal/min (gpm) and 65 gpm, capital costs are estimated at $85,000 and $115,000, respectively. Estimated operating costs (excluding sludge disposal) typically ranged from $0.30 to $0.70 per 1000 gal of groundwater containing up to 100 parts per million (ppm) of metals. Sludge disposal may increase operating costs by approximately $0.50 per 1000 gal of groundwater treated. Actual sludge disposal costs (including fixation and transportation) have been estimated at approximately $300 per ton of sludge (D16512I, p. 9).

In specific cases, the operating costs for the removal of manganese (initial concentration of 6 ppm) and iron (initial concentration of 15 ppm) from groundwater to levels of 0.04 and 0.3 ppm, respectively, have been estimated at $0.40 per 1000 gal of groundwater. These operating costs assume 2 hr per shift of operating labor (D16512I, p. 9).

Information Source

D16512I, NEESA, 1993

T0163

Chem-Nuclear Systems, Inc.

Thermex

Abstract
Thermex™ is a commercially available ex situ technology that is based on the use of membrane separation technology for preconcentrating plant radioactive wastewater and evaporation for drying the preconcentrates. The technology is designed to minimize the volume of waste that would require storage or disposal.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0164

ChemPete, Inc.

Bioremediation

Abstract
ChemPete, Inc., bioremediation is an effective and continuous cleanup method for transforming gasoline, diesel fuel, fuel oil, kerosene, and chlorinated solvents to nonhazardous organic matter, carbon dioxide, and water, according to the vendor. ChemPete uses bacteria, nutrients, and a catalyst developed by Alpha Environmental Biosystems, Inc. ChemPete was the first company to achieve closure of both gasoline and fuel oil sites in situ in accordance with Illinois' rigorous closure guidelines (5 parts per billion benzene). RIMS was unable to contact the vendor, and the commercial availability is unknown.

The ChemPete bioremediation technology works under buildings, roads, and other structures that would have to be demolished to apply many other technologies. The ChemPete technology can be used in conjunction with soil vapor extraction. Preliminary tests on bioremediation of nickel, in which the valence state is changed rendering it insoluble, have also been conducted.

Materials, such as strong acids, strong bases, biocides, or soils heavily contaminated with solvents, would interfere with this technology. Tight clays have the tendency to slow down the propagation of the bacteria due to tight soil structures. With certain salts, the soil pores can be kept open to allow the bacteria access to the contaminants. All information is from the vendor and has not been independently verified.

Technology Cost
According to the vendor, the cost of this technology is from \$30 to \$50 yd^3. The type of soil makes the largest difference in the cost (D10182W, p. 33).

Information Source

D10182W, VISITT 4.0, 1995

T0165

Cherokee Environmental Group

The BioSolution

Abstract
Using its 16 brick kilns, 4 fixed-site bioremediation facilities, and 1 water treatment plant, the Cherokee Environmental Group (CEG), with its BioSolution technology, can remediate and recycle any mineral, clay, silt, sand, soil, or water contaminated with:

- Gasoline
- Gasohol, jet fuel, kerosene
- No. 2, 4, 5, and 6 fuel oil
- Motor oils and waste motor oils
- Hydraulic oils
- Transmission fluids
- Lubricating/cutting oils
- Naphthalene
- Mineral oils
- Mineral spirits, including stoddard solvent and varsol

as long as the material is not classified as a hazardous waste or substance under any Maryland, North Carolina, South Carolina, or federal regulation. In 1988, Cherokee obtained permits for its brick manufacturing plants to allow the blending of nonhazardous, petroleum-contaminated soils and industrial by-products into the virgin clay/shale soils. Cherokee discovered that some clays and shales used in brick manufacturing can accommodate most petroleum-contaminated soils and industrial by-products while still maintaining brick quality standards. Because not all petroleum-contaminated soils are suitable for brick manufacturing, CEG began using bioremediation in 1993 to complement its brick making technology. The products of the technology include construction-grade brick, brick chips, clean soil, clean water, and recovered petroleum product that is recycled as fuel. This technology is commercially available.

Construction debris disposal is not part of the service routinely offered; an additional fee is added for soils containing an excess of foreign debris. Materials must be tested for ceramic compatibility and environmental compliance prior to use in brick making. The ceramic testing includes strength, shrinkage, and aesthetics.

Technology Cost

No available information.

T0166

Cintec Environment, Inc.

Circulating Fluidized-Bed Combustor

Abstract

The circulating fluidized-bed combustor (CFBC) is an incineration technology that has been adapted for the ex situ thermal destruction of organic contaminants in soils, sludges, or liquids. The CFBC technology uses a high-turbulence incineration bed, which ensures thorough mixing and efficient gas–solid contact with the contaminated materials.

This technology can treat materials contaminated with a wide range of organic contaminants, including solvents, volatile organic compounds (VOCs), and semivolatile organic compounds (SVOCs). CFBC is particularly suited for the treatment of media contaminated with polychlorinated biphenyls (PCBs).

This technology has been successfully used in the field several times, and is commercially available from Cintec Environment, Inc., of Quebec, Canada.

According to the Committee for the National Institute for the Environment, the technology has several advantages:

- Operates at lower temperatures than other combustors, reducing technology costs.
- Has a simple design and long life.
- Produces minimal NO_x emissions.

This technology is ineffective in the treatment of inorganic contaminants. High-density wastes do not mix well with the forced air and reduce process efficiency.

Technology Cost

The U.S. Department of Energy's (DOE's) Los Alamos National Laboratory (LANL) conducted a cost analysis of the circulating fluidized-bed combustor based on the full-scale remediation of a former oil field on the Kenai Peninsula in Alaska. The LANL determined that the remediation cost ranged from $150 to $300 per ton when treating 20,000 to 50,000 tons of soil. For the treatment of 10,000 to 15,000 tons of contaminated soil, the cost ranged from $350 to $400 per ton. These estimates exclude the cost of excavation (D21225Z, p. 63).

The costs associated with this technology will vary with a number of factors:

- Type and concentration of contaminants
- Matrix containing the contaminants
- Percentage of chlorinated compounds in the waste
- Volume of material to be treated (D15791Z, p. 2)

Information Sources

D15791Z, Enviro-Access Centre web site, 1995
D21225Z, Los Alamos Laboratory, 1996

T0167

Clean Technologies

Pyrodigestion

Abstract

Pyrodigestion is an ex situ thermal and chemical treatment technology. This technology uses a molten alloy of metals (principally aluminum) in an anaerobic atmosphere to destroy virtually any organic contaminant and to absorb most metal contaminants into the metal bath. Contaminated materials are added to the liquid metal bath where they are broken down into elemental components, nonhazardous compounds, and simple salts.

According to the vendor, this technology has 10 patents (issued or pending). This technology is currently commercially available.

Limitations of pyrodigestion have been listed as including mercury contaminants. Because mercury vaporizes at a much lower temperature than the operating range of the molten aluminum bath, expensive condensers, and other complex methods for capturing the mercury after treatment would have to be employed. According to the vendor, however, while this may slightly complicate the process, it is not perceived as a major difficulty or technical limitation. The gas must be cooled following treatment, and typically this is accomplished utilizing sprayers or scrubbers. The volatile metals condense in the water and precipitate and are removed for recycling.

Another limitation is an excessive amount of moisture in the materials being treated. Field tests have demonstrated the moisture content of the material being treated can be as high as

50%. Any material with moisture content above this level creates too much steam for the system to be able to absorb without reducing the rate of feed of wet contaminated materials. According to the vendor, this limitation is economical rather than technical. Fifty percent moisture does not limit the performance of the process, but it increases the energy costs.

Technology Cost

The cost for this technology is $200 to $300 (1995 dollars) per cubic yard of waste treated. These estimates do not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals (D101791, p. 13). According to the vendor, this cost estimate was developed on a model that included reasonable pre- and postprocessing, capital, labor and equipment, residuals, and excludes permitting costs. Obviously the nature of materials to be treated is site specific and can dramatically affect the cost per cubic yard (personal communication, David Smith, 1/20/98).

Factors that have a significant effect on unit price include the following:

- Labor rates
- Site preparation
- Depth of contamination
- Utility/fuel rates
- Moisture content of soil
- Quantity of waste
- Amount of debris with waste
- Characteristics of soil
- Characteristics of residual waste
- Waste handling/preprocessing (D101791, p. 13)

Information Source

D101791, VISITT Version 4.0, 1995

T0168

CleanSoil Inc.

CleanSoil Process

Abstract

The CleanSoil process is an ex situ treatment technology that uses steam to remove hydrocarbons and chlorinated solvents from contaminated soils. The steam vaporizes the contaminants from the soil and carries them to a condenser for recovery. The water is converted back into steam and reused in the system. The remaining vapors pass through an activated carbon filter and are released into the atmosphere. The technology has been applied full-scale at multiple sites and is commercially available.

According to the vendor, the CleanSoil process has several advantages:

- Treats contaminated soil on-site.
- Is cost efficient.
- Requires little assembly time.

TABLE 1 Cost Estimates for the CleanSoil Technology for 7500 yd^3 of Soil

Sales value at \$55.00/yd^3 or \$37.00/ton	\$412,500
Fixed Costs	
Amortization at 5 years—estimated \$3,000/month	\$36,000
Annual maintenance	\$8,000
Total fixed costs	\$44,000
Variable costs	
Fuel 1.25 gal/yd^3 at \$1.00/gal	\$9,500
Disposable components (filters, carbon, etc.)	\$7,500
Unit manager at \$30,000 annual salary	\$30,000
One full-time helper at \$10/hr (1500 hr)	\$15,000
Fringe benefits at 40%	\$18,000
Monthly maintenance at \$500/month	\$6,000
Miscellaneous (water, trucking, etc.)	\$4,000
Total variable costs	\$90,000
Total operating costs	\$134,000
Operating margin	\$278,500
Percent margin	68%
Cost/cubic yard	\$17.87
Cost/ton	\$11.91

Source: Adapted from D15470L.

- Has a compact design.
- Operates as a closed-loop system.
- Reclaims contaminants for recycling.

All information was provided by the vendor and has not been independently verified. This technology does not treat soils contaminated with metals and is only applicable to organic compounds that can be volatilized by steam.

Technology Cost

In 1996, the vendor prepared cost estimates for CleanSoil treatment of 7500 yd^3 of soil. More specifically, the projections were based on processing the waste 10 hr per day for 150 days per year at a rate of 5 yd^3/hr. Table 1 discusses these cost estimates. According to the vendor, these estimates were intended to provide realistic operating costs based on the company's experiences. The projections were not intended for use by a startup company. Any expenses normally classed as "general and administrative" were not included. Numbers that are representative of the conditions at a specific project area should be inserted into the table for the most accurate estimates (D15470L).

There are two basic models of CleanSoil machines. The standard 5-ton/hr unit is the Model CSI -200. The model CSI-1200 M has a capacity of up to 40 tons/hr. The vendor states that the CSI-200 typically costs \$165,000, and the CSI-1200 costs approximately \$430,000. According to the vendor, refurbished machines sell for under \$100,000 (D18216L, p. 2; D22051Z, p. 1; D220520).

Information Sources

D15470L, vendor information

D18216L, vendor literature

D22051Z, CleanSoil, Inc., undated

D220520, Global InterMark Corp., undated

T0169

Clemson University

Sintered Ceramic Stabilization

Abstract

The U.S. Department of Energy (DOE) is researching technologies for the stabilization and immobilization of fly ash contaminated with radionuclides and metals that will reduce waste material volume and consistently satisfy regulatory requirements. The Mixed Waste Focus Area (MWFA), a DOE/EM-50 program, has stated the need for improved stabilization methods that would accept higher ash waste loadings. To address these issues, the MWFA has invested in a sintered ceramic stabilization technique developed by Clemson University.

Clemson's sintered ceramic stabilization (SCS) technology is applicable to most inorganic homogenous solids or sludges, including ash, dry particulate, incinerator blowdown residues, soils, and wet particulate. The process combines the contaminated material with a high iron/high potassium aluminosilicate material, such as the naturally occurring red roan formation (RRF) clay, which stabilizes the wastes through mixing and heating. This process converts the waste components into crystalline and noncrystalline phases within a fired ceramic waste form.

SCS can treat a wide range of compositions, including most inorganic materials, excluding highly volatile species like mercury. Waste streams containing organic content may be suitable feeds for the SCS process and the organic contaminants in a vapor state can react readily with the RRF mineral to rapidly form condensed-phase reaction products.

Bench-scale treatability tests on contaminated wastewater sludge and soil have been performed using the SCS technology. A drum-scale demonstration of the process is planned for 1999.

The Clemson SCS process is not well suited for treating aqueous and organic liquids, highly volatile species, and unique mixed wastes, such as explosives or oxidizers. A possible secondary waste generation can result from volatilization during the thermal processing. These off-gases can be captured and treated with the use of a scrubbing system.

Technology Cost

Although no methodology has been selected for evaluating the costs associated with full-scale deployment of Clemson's SCS technology, approximately $200,000 has been spent on equipment needed for the pilot-scale demonstration. This includes the purchase and installation of the required mixers, extruders, and furnaces to treat the 100 kg of U.S. DOE Waste Experimental Reduction Facility (WERF) incinerator fly ash.

Information Source

D19411Q, Innovative Technology (DOE), December 1998

T0170

Clyde Engineering Service

Metals Removal

Abstract

Clyde Engineering Services has two patents for metals removal processes in which bacterial cells are attached to porous fiber webbing through which aqueous wastes are passed. Specific bacteria are selected based on their ability to retain the target metal.

Neither of the Clyde Engineering metals removal technologies are currently commercially available; however, Clyde Engineering Service is willing to sell the patent (U.S. # 4,530,763) for one of the technologies (personal correspondence, Robert Clyde, Clyde Engineering, 1/17/97). No full-scale application has been completed for either technology.

Certain bacteria are selected based on their ability to attach to specific metals. These bacteria are then grown in a nutrient broth and then placed in contact with a porous synthetic fiber such as Dacron®, Orlon®, or Tyvek fiber. Wastewater is then brought into contact with these bacteria-coated fibers, and specific metals in the wastewater attached to the bacteria on the fibers. The metals are removed from the fibers through washing, burning, contact with sodium carbonate, or by some means.

These technologies are not applicable to organic contaminants. No information is given on acceptable concentrations of contaminants in the feed stream. Some concentrations of contaminants and/or co-contaminants may be toxic to the bacteria. There is also no way of knowing if the removal efficiency is adequate to make this a practical technology.

Technology Cost
No available information.

T0171

CMI Corporation

Enviro-Tech Thermal Desorption

Abstract
The Enviro-Tech™ thermal desorption system is an ex situ thermal treatment technology that can be set up in two different configurations. The A mode is used to treat soils contaminated with lighter-end hydrocarbons, and the C mode is used to treat soils contaminated with heavier fractions. A B mode is also available. It is identical to the A mode except that it uses high-temperature ceramic fiber bags for the fabric filter baghouse. The system can treat volatile organic compounds (VOCs), polyaromatic hydrocarbons (PAHs), and total petroleum hydrocarbons (TPH). The technology is commercially available through Midwest Soil Remediation, Inc.

Technology Cost
At Fort Lewis Army Base in Washington, an Enviro-Tech thermal desorption system was installed to treat 104,336 tons of PAH-contaminated soil. Initial PAH concentrations in soils averaged 2.2 mg/kg and ranged from 0.6 to 4.2 mg/kg. During full-scale operation, the unit reduced PAH concentrations to levels ranging from below detection limits to 0.44 mg/kg (D220917, pp. 1, 5, 14). Total costs for the project were $7,094,767, including $3,532,270 for thermal desorption treatment. Total remedial action costs were about $68 per ton of treated soil, and costs for thermal desorption treatment alone were $34 per ton (D220917, pp. 13,14).

Information Source

D220917, U.S. Army Corps of Engineers, 1998

T0172

Combustion Process Manufacturing Corporation

CPMC Process

Abstract
Combustion Process Manufacturing Corporation (CPMC) developed a new incineration process known as the CPMC process. The process uses two separate burner stages: a low-temperature

starved air stage and a high-temperature, enhanced-air stage. According to the developer, this design allows removal of toxins and toxin precursors prior to exposure to high temperatures and oxygen levels. In addition, subsystems for particulate extraction, materials recycling, and energy reclamation are included in the process.

According to the developer, the process is capable of treating waste such as oilfield reserve pits, lagoon waste, hazardous waste (e.g., medical, etc.), municipal waste, contaminated soil, and volatile organic compounds (VOCs), and general port or terminal waste.

Careful control of operating conditions is required for optimum performance, and the system is controlled by a PC-type computer to monitor sensors and to adjust air, fuel, and material feed rates.

The technology is commercially available.

Technology Cost
No available information.

T0173

Commodore Applied Technologies, Inc.

Solvated Electron Technology (SET)

Abstract
The Solvated Electron Technology (SET™) is an ex situ process designed for the separation of nuclear wastes from other hazardous materials. The technology combines gravimetric separation, chelation, and contaminant dissolution. SET concentrates the radioactive portion of the mixed waste while neutralizing certain other contaminants, such as polychlorinated biphenyls (PCBs). According to Commodore Applied Technologies, Inc. (Commodore), SET can effectively treat and decontaminate soils and other media such as sludges and sediments. Commodore claims that SET can destroy PCBs, pesticides, dioxins, chlorinated substances, chemical and biological phosphates, and other toxic contaminants to an extent that satisfies current federal environmental guidelines. The vendor also asserts that the process can treat oils and other hydrocarbon liquids, in addition to metals. At this time, however, Commodore has only used the SET process in either bench-scale or treatability study applications.

Previous studies have shown that water, iron (including iron-related compounds), oxygen, and carbon dioxide (all found in soil) have adverse effects on solvated electrons. According to Commodore, the SET process can be applied to soil successfully in the presence of these competing substances. Presently, Commodore has used the SET process in either bench-scale or field treatability study applications.

In April 1996, it was announced that Commodore's SET technology had been selected by the Department of Commerce as one of 10 innovative technologies for the Rapid Commercialization Initiative.

Technology Cost
In 1995, Commodore estimated that the cost of treating wastes with the Solvated Electron Technology (SET) would range from \$100 to \$175 per ton. Factors cited as having a significant impact on project costs are (in descending order of importance) the moisture content of the soil, the characteristics of the soil, the amount of debris associated with the waste, the quantity of waste treated, the initial contaminant concentration, and the target contaminant concentration. It was noted in this estimate that all indirect costs may not be included (D10175X, p. 14).

Information Source

D10175X, VISITT 4.0, 1995

T0174

Commodore Separation Technologies, Inc.

Supported Liquid Membrane

Abstract
The supported liquid membrane (SLM) technology allows metal ions to be separated from aqueous media. The SLM technology uses a liquid membrane that is immobilized in the pores of a polymeric support to perform separations. In theory, the fastest transfer through an SLM will be reached when a series of carrier molecules are aligned and allow the exchange of the solute (metal) between them. SLMs must be optimized for each carrier and solute. Although SLMs were invented in the early 1970s, the bulk of experimental studies for metals removal has been carried out in the last 10 years. Commodore Separation Technologies, Inc., intends to commercialize this technology.

SLMs are not the best approach for removing suspended particles since good filtration is required to avoid membrane fouling. Thus far, no tests have been performed on a large-scale commercial basis.

Technology Cost
In 1996, costs for SLM technology treatment of a wastewater system typical of that found in the nickel-plating industry were compared to those for reverse osmosis treatment of the same amount of wastewater. It was assumed that wastewaters would be processed at a feed rate of 30/gal min, 15 hr/day, and 20 days/month. It was also assumed that a total of 175 lb of nickel sulfate, 45 lb of nickel chloride, and 225 lb of chromium salts would be removed.

The economic analysis favored the SLM technology. About $890 was saved through recovery of raw materials (nickel and chromium). Costs for the SLM treatment technology included:

- Capital investment in SLM system to recover both nickel and chromium—$47,000
- Membrane replacement costs, per day—$15.62
- Electricity costs, per day—$2.63
- Pump maintenance costs, per day—$7.75
- Solvent recovery costs, per day—$3.00

Information Source

D15565R, Kilambi, 1996

T0175

Composting—General

Abstract
Composting is a bioremediation technology that can be applied to soils and sediments contaminated with biodegradable organic contaminants. Contaminated materials are combined with organic matter, creating an environment in which microorganisms can degrade the contaminants. Composting has been used for many years by gardeners to degrade organic material into fertilizer.

All materials and equipment used for composting are commercially available.

The following factors may limit the applicability and effectiveness of the process:

- Substantial space is required for composting.
- Excavation of contaminated soils is required and may cause the uncontrolled release of volatile organic compounds, if they are present.
- Composting results in a volumetric increase in material because of the addition of amendment material.
- Heavy metals are not treated by this method and can be toxic to the microorganisms.
- Some contaminants may only be partially decomposed. In some cases the decomposition products may be more toxic than the original contaminant.
- Some contaminants can become strongly bound to the compost matrix and not be detected using standard extraction procedures. In some cases these compounds have appeared to have been degraded, only to be detected at later times.

Technology Cost
Composting costs will vary with the amount of soil to be treated, the soil fraction in the compost, availability of amendments, type of contaminant, and type of process (i.e., windrow, aerated static pile, or agitated in-vessel composting). Estimated costs, as of 1994, for full-scale windrow composting of explosives-contaminated soil are approximately \$190/yd^3 for soil volumes of approximately 20,000/yd^3. Estimated costs for static pile composting and mechanically agitated in-vessel composting are higher. Composting may be an economic alternative to thermal treatment when cleanup criteria and regulatory requirements are suitable (D10858H, p. 39).

Information Source

D10858H, Remediation Technologies Screening Matrix and Reference Guide, 1994

T0176

Concurrent Technologies Corporation

Acid Extraction Treatment System (AETS)

Abstract
The acid extraction treatment system (AETS) reduces the concentrations and/or leachability of heavy metals in contaminated soils so that the soils can be returned to the original site. The main application of the AETS is to extract heavy metals from soils. Additional applications of the AETS include treatment of contaminated sediments, sludges, and other heavy-metal-containing solids.

The AETS system has been tested on a variety of soils containing one or more of the following metals: arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The AETS system can treat all soil fractions, including fines.

According to Concurrent Technologies Corporation, this technology is no longer being studied.

Technology Cost
Treatment costs for the AETS (under expected process conditions) range from \$100 to \$180/yd^3 of soil (October 1995), depending on the site size, soil types, and contaminant concentrations. Operating costs range from \$50 to \$80/yd^3 of soil (D10777H, p. 275). Operating costs include labor (personnel); maintenance and engineering; equipment maintenance costs; and utilities, chemicals, disposal, and reseeding (D12850H, p. 44).

Table 1 contains AETS cost summaries (from a 1994 report) for the AETS operating at the following feed rates: 10, 15, 20, and 30 yd^3/hr (D12850H, p. 43).

TABLE 1 AETS Cost Summaries under Various Conditions

Process and Site Parameters					Costs		Total Cost per yd^3	
Feed Rate (yd^3/hr)	Time[a] (min)	Percent Fines[b]	Metal Levels (mg/kg)	Site Size (1000 yd^3)	Capital Costs (million $)	Operating Costs ($/$yd^3$)	Capital Paid Off over One Site ($/$yd^3$)	Capital Paid Off over Two Sites ($/$yd^3$)
30	24	15 (2)	5,000	150	4.5	41	83	71
20	24	15 (2)	5,000	100	3.6	51	104	88
20	36	30 (25)	15,000	60	4.5	82	178	147
20	24	15 (25)	15,000	80	4.1	71	141	121
15	24	15 (2)	5,000	60	3.2	61	133	111
15	36	30 (25)	15,000	30	3.8	92	243	191
15	36	15 (2)	5,000	30	3.3	61	189	146
10	36	30 (25)	15,000	20	3.2	112	301	237

Source: EPA, August 1994, (D12850H, p. 43).
[a]Extraction residence time in minutes.
[b]Particle size less than 50 μm; number in parenthesis is percent of fines disposed.

Information Sources

D10777H, U.S. EPA SITE Emerging Technology Program, October 1995
D12850H, U.S. EPA, August 1994

T0177

Conor Pacific Environmental Technologies, Inc.

WINDsparge

Abstract

Conor Pacific Environmental Technologies, Inc. (Conor Pacific), has developed the WINDsparge windmill-powered remediation system for the in situ bioremediation of petroleum hydrocarbons at remote sites where utilities are unavailable. These systems use wind power and naturally occurring soil bacteria to clean up soil and groundwater contamination. Although WINDsparge typically is used to power air sparging systems, the technology may be adapted to incorporate soil vapor extraction, dual-phase extraction, pump-and-treat, and engineered biocell technologies.

The WINDsparge system is commercially available from Conor Pacific Environmental Technologies, Inc.

According to the vendor, WINDsparge systems have several advantages:

- Are inexpensive.
- Operate on wind power and solar power.

- Require little maintenance.
- Are easily transportable and install in less than 2 days.
- Come equipped with a protection system that shuts off the windpump at high speeds.

All information has been supplied by the vendor and has not been independently verified.

Technology Cost
According to the vendor, a typical WINDsparge system costs $9700. This cost includes the windmill, pulse tank, control valves, and system piping (D19961F, p. 1). Additional costs incurred will include system installation, well installation, site monitoring, and maintenance.

Information Source

D19961F, Conor Pacific Environmental Technologies, Inc., 1999

T0178

Constructed Wetlands — General

Abstract
A constructed wetland is an engineered treatment technology designed to mimic the chemical, physical, and biological mechanisms of a natural wetland. The plants, soil, microorganisms, and physical design of the wetland work together to remove heavy metals; radionuclides; suspended solids; pathogens and other microorganisms; inorganic compounds; nonmetals; cyanides; fats, oils, and grease; total petroleum hydrocarbons (TPH); volatile organic compounds (VOCs); halogenated VOCs; polycyclic aromatic hydrocarbons (PAH); benzene, toluene, ethylbenzene, and xylenes (BTEX); halogenated organic solvents; pesticides; herbicides; sewage; biological and chemical oxygen demand (BOD and COD); creosote; and explosives from contaminated groundwater, wastewater, surface water, and leachate.

Constructed wetlands are commercially available through a number of vendors and have been used to treat water contaminated with acid mine drainage, explosives, hydrocarbons, chlorinated solvents, phenols, agricultural wastes, and sewage. The RIMS2000 database discusses constructed wetlands for the treatment of acid mine drainage in summary number T0179.

Some of the advantages of a constructed wetland treatment system are that it:

- Has little or no operation and maintenance cost.
- Uses no electricity after construction is complete.
- Is capable of permanently degrading organic contaminants.
- Provides protection against floods and erosion.
- Creates wildlife habitat.

The performance of a constructed wetland may be limited by its design criteria. The system may take several growing seasons to reach at design capacity. Freezing conditions can limit the effectiveness of a constructed wetland. Constructed wetlands do not destroy metals. The long-term effectiveness of constructed wetlands in unknown. Efficiency may decrease over time. Wetland wildlife may be adversely affected by the accumulation of heavy metals in wetland plants. Some constructed wetlands have attracted problem wildlife species.

Technology Cost
Constructed wetlands are a passive treatment system. Therefore, operation and maintenance costs are very low compared to that of active treatment processes (D10500Q, p. 1). Construction costs vary considerably from site to site. Constructed wetlands may be not be financially viable at all sites (D20499J, p. 2).

RIMS2000 summary number T0179 discusses the specific costs associated with building and maintaining a constructed wetland for the treatment of acid mine drainage.

Information Sources

D10500Q, U.S. EPA, 1993

D20499J, Federal Remediation Technologies Roundtable, undated

T0179

Constructed Wetlands for Treatment of Acid Mine Drainage — General

Abstract

Constructed wetlands use biological processes inherent in natural wetlands and a system designed to optimize those processes to treat wastewater contaminants specific to a particular site. Constructed wetlands are passive treatment systems that mimic, rather than overcome, natural processes. Consequently, the cost of operation and maintenance is significantly lower than for active treatment systems.

Constructed wetlands are commercially available through a number of vendors and have been used to treat water contaminated with acid mine drainage, explosives, hydrocarbons, chlorinated solvents, phenols, agricultural wastes, and sewage. The RIMS2000 database discusses the other applications-constructed wetlands technology in summary number T0178.

According to a constructed wetland consulting company, some of the advantages to a constructed wetland are that it:

- Is cost effective.
- Has little or no operation and maintenance costs.
- Uses no electricity.
- Creates wildlife habitat.

Constructed wetlands may not be applicable to all sites. The site must have the proper conditions to produce and support a wetland. The performance of a constructed wetland may be limited by its design criteria. Freezing conditions can limit the effectiveness of a constructed wetland. The long-term effectiveness of constructed wetlands in unknown. Wetland wildlife may be adversely affected by the accumulation of heavy metals in wetland plants.

Technology Cost

At the Fabius Coal Preparation Plant in Jackson County, Alabama, a constructed wetland treatment system was built to treat acid drainage from a coal pile. In 1985, the total cost of the wetlands was $43,000. The annual costs from 1985 to 1990 were approximately $13,000 due to repairs and extensive monitoring. In 1991, operation and maintenance costs were estimated to be $1000 annually (D12459E, p. 164).

In 1990, an anoxic limestone drain was installed upstream of a wetland treating acid drainage from another coal-contaminated area of the Fabius Coal Preparation Plant. The total installation cost was approximately $19,000 (D124607, p. 135).

In 1986, a wetland system was installed to reduce acid mine drainage from the closed Tennessee Valley Authority (TVA) 950 Coal Mine near Flat Rock, Alabama. The system cost $41,000 to build. Annual monitoring costs were $3700. Before the wetland system was installed, TVA spent $28,500 annually to chemically treat the acid mine drainage (D204502, p. 2).

In Pennsylvania, a two-celled aerobic wetland was designed to treat 5.2 gal of acid mine drainage per minute. In 1992, the system cost approximately $15/m^2 to build (D204273, p. 5).

In 1995, the Somerset County Conservation District in Somerset County, Pennsylvania, constructed wetland treatment systems and limestone drains at four separate locations in the Oven Run/Pokeytown Run watershed. The estimated cost of the Oven Run/Pokeytown Run Project was $5.2 million (D204284, p. 34).

Constructed wetlands are a passive treatment system. Therefore, operation and maintenance costs are very low compared to that of active treatment processes (D10500Q, p. 1).

The cost of building a constructed wetland varies considerably from site to site. Constructed wetlands may be not be financially viable at all sites (D20499J, p. 2).

Knight-Piesold and Company, a constructed wetlands vendor, estimated the costs associated with three hypothetical coal mine sites and three Canadian metal mine acid rock drainage sites. Raw capital costs for aerobic constructed wetlands systems at the coal mine sites ranged from $310,000 to $2,880,000. Net present value cost per kilogram of metal removed ranged from $0.32 to $0.46. Raw capital costs for anaerobic constructed wetlands systems ranged from $5,208,000 to $26,626,000. Net present value cost per kilogram of metal removed ranged from $0.37 to $0.40 (D12114S).

For the purposes of estimating technology cost, certain assumptions were made by Knight Piesold and Company regarding design criteria and wastewater chemistry. These assumptions are:

- The wastewater chemistry is relatively simple and aluminum and iron(III) are not present in the waste stream.
- An anoxic limestone drain is considered a sufficient method of adding alkalinity to acid rock drainage.
- Unit cost values for excavation, geomembranes, or clay cell liners and other construction costs are identical for both anaerobic and aerobic passive-treatment systems.
- Flow rates range from 6.2 to 300 liters/sec.
- pH ranges from 2.3 to 4.5.
- Metal concentration ranges are as follows:

Iron 250 to 800 mg/liter
Copper 0 to 120 mg/liter
Zinc 0 to 80 mg/liter
Manganese 0 to 20 mg/liter
Lead 0 to 5 mg/liter.

The parameter ranges listed in the above assumptions have been successfully treated by constructed wetland technology on a pilot- or full-scale basis (D12114S).

For the anaerobic cells of the constructed wetlands systems, organic substrate represented more than 50% of the cell capital cost. The anaerobic substrate was conservatively estimated to cost $32.70/m^3$ (D12114S).

Information Sources

D10500Q, U.S. EPA Superfund Innovative Technology Evaluation, 1993
D12114S, Gusek and James, 1995
D12459E, Brodie, 1993
D124607, Brodie et al., 1993
D204273, Skousen, undated
D204284, SCRIP, undated
D204502, Heath, 1999
D20499J, Federal Remediation Technologies Roundtable, undated

T0180

Constructed Wetlands for Explosives Contamination — General

Abstract

Constructed wetlands are engineered systems designed to mimic the physical, chemical, and biological mechanisms of a natural wetland. Wetlands may be constructed above ground to resemble natural wetlands such as swamps, bogs, and marshes; or they may treat contaminated water below the surface. Constructed wetlands have been used for the ex situ treatment of groundwater contaminated with explosives.

Constructed wetlands are commercially available through a number of vendors and have been used to treat water contaminated with explosives, hydrocarbons, chlorinated solvents, phenols, acid mine drainage, agricultural wastes, and sewage. The RIMS2000 database discusses constructed wetlands in general in summary number T0178 and constructed wetlands for the treatment of acid mine drainage in summary number T0179.

According to a constructed wetland consulting company, some of the advantages to constructed wetlands are that they:

- Are cost effective.
- Have little or no operation and maintenance costs.
- Create wildlife habitat.

The performance of a constructed wetland may be limited by its design criteria. The system may take several growing seasons to reach design capacity. Freezing conditions can limit the effectiveness of a constructed wetland. Constructed wetlands do not destroy metals. The long-term effectiveness of constructed wetlands is unknown. Treatment efficiency may decrease over time. Wetland wildlife may be adversely affected by the accumulation of heavy metals in wetland plants. Some constructed wetlands have attracted problem wildlife species.

Technology Cost

Constructed wetlands are a passive treatment system. Therefore, operation and maintenance costs are very low compared to that of active treatment processes (D10500Q, p. 1). Construction costs vary considerably from site to site.

The regional temperature variations, rainfall, patterns, groundwater flow characteristics, explosive type, explosive concentration, presence of other contaminants, land value, and other regulatory requirements can affect the wetland's cost. Constructed wetlands may not be financially viable at all sites (D20499J, p. 2; D20503Y, p. 30).

The U.S. Navy estimated that constructed wetlands used to treat explosive compounds would cost \$0.15 to \$1.00 per 1000 gal of influent. The major cost contributors were land acquisition; grade, fill, and weir construction; establishing plant growth; long-term inspection; site supervision; site quality assurance and health and safety support; and sampling and analysis for process control. Indirect costs such as project management, design and engineering, vendor selection, home office support, permit preparation and fees, regulatory interaction, site characterization, treatability testing, performance bond, and contingencies were not included in the estimate (D207045, p. 2).

The costs of a 10-acre, full-scale, gravel-based constructed wetland used to teat groundwater contaminated with explosive compounds were calculated based on the field demonstration at the U.S. Department of Defense's (DOD's) Milan Army Ammunition Plant near Milan, Tennessee. The estimated, site-specific costs of a 200-gal/min system that discharges effluent to surface waters were \$3,466,000 in 1998 dollars. Amortization of these costs was estimated at \$1.36 per 1000 gal of effluent for 10 years and \$0.45 per 1000 gal for 30 years. Table 1 shows a breakdown of the site-specific estimate. Capital costs for a similar system with groundwater

TABLE 1 Estimated, Site-Specific Cost for a Full-Scale, 200-gal/min, Gravel-Based Wetland for the Treatment of Explosive Compounds (Surface Water Discharge)

Item	Cost
Direct Costs	
Excavation and fill	$82,180
Gravel fill	$840,238
Liner	$754,500
Pumps	$12,115
Tanks	$8,754
Instruments	$28,079
Insulation	$16,351
Piping	$151,673
Walls and structures	$157,033
Foundations	$52,886
Electrical	$35,929
Cleanup and painting	$1,188
Planting	$34,399
Miscellaneous (survey, soil tests, overhead, etc.)	$252,026
Indirect Costs	
Health and safety	$12,474
Bid contingency, 15% of direct cost	$364,102
Scope contingency, 15% of direct cost	$364,102
Engineering services during construction	$150,328
Engineering and design	$147,332
Total site-specific costs	$3,465,687

Source: From D20503Y.

TABLE 2 Operation and Maintenance Costs for a Full-Scale, Gravel-Based Wetlands with Surface Water Discharge

Item	Annual Cost ($/Year)	Basis
Maintenance		
Berms	4,000	10 acres at $400/ acre
Pumps	485	4% of direct cost
Tanks	350	4% of direct cost
Walls and structures	6,281	4% of direct cost
Pipes	6,067	4% of direct cost
Electrical equipment	1,437	4% of direct cost
Instruments	1,123	4% of direct cost
Raw Materials		
Carbon source	14,334	357 lb/day for 365 days at $0.11/lb
Phosphate source	1,200	5.45 tons/year at $220/ton of fertilizer
Electricity	6,400	106,670 kWh/year at $0.06/kWh
Operator	15,800	20% of one operator's time at $79,000/ year
System effluent monitoring	5,200	52 samples at $100/sample
Total costs	62,677	

Source: From D20503Y.

reinjection were estimated at $4,125,000. The operation and maintenance (O & M) costs associated with this wetland were estimated to be $62,677 per year. Table 2 provides a detailed O & M cost estimate for the full-scale constructed wetland. Assuming a 95% system availability and a 30-year life, the estimated total (capital and O & M) costs were $1.78 per 1000 gal (D20503Y, pp. 5, 25; D20499J, p. 4; D20502X, p. 1).

Information Sources

D10500Q, U.S. EPA, 1993

D20499J, Federal Remediation Technologies Roundtable, undated

D20502X, Environmental Security Technology Certification Program, undated

D20503Y, Environmental Security Technology Certification Program, 1999

D207045, U.S. Navy, undated

T0181

Contamination Technologies, Inc.

Low-Temperature Thermal Absorber

Abstract

The Contamination Technologies, Inc. (CTI), low-temperature thermal absorber (LTA) is an ex situ rotary kiln thermal stripping technology. The use of aerospace ceramic material enhances the ability of the kiln to operate at the temperatures necessary for high efficiency while maintaining a high throughput.

RIMS was unable to contact the vendor.

According to the vendor, soils with high moisture content may slow processing time.

Technology Cost

According to the vendor, the cost for this technology is $50 to $150 (1995 dollars) per ton. This estimate does not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals.

Factors that have a significant effect on unit price include the following:

- Initial contaminant concentration
- Moisture content of soil
- Quantity of waste
- Characteristics of soil
- Target contaminant concentration
- Labor rates
- Utility/fuel rates
- Amount of debris with waste
- Waste handling/preprocessing
- Site preparation (D10174W, p. 10)

Information Source

D10174W, VISITT Version 4.0, 1995

T0182

ConTeck Environmental Services, Inc.

Soil Roaster

Abstract

Soil roaster is a thermal desorption process specifically designed for the treatment of petroleum-contaminated soils, which is offered by ConTeck Environmental Services, Inc. According to the vendor, soil roaster is particularly designed for treating wet clay soils with a high potential for dust and feed equipment plugging. This technology is commercially available.

Soils contaminated with high levels of organically bound sulfur compounds require the use of additional wet scrubbing. Soils contaminated with high levels of organically bound chlorine compounds require the use of additional wet or dry scrubbing equipment. Soils containing heavy metals may require additional posttreatment processes to stabilize or remove the metals.

Thermal desorption units can experience treatment failures when contaminant condensation occurs inside the baghouse. According to the vendor, the ConTeck system minimizes, but does not yet completely eliminate, this problem.

This technology cannot be located near noise-sensitive areas. The operating system does not work well in temperature extremes, such as below 30 or above 100°F. The technology is ex situ, requiring soil excavation. The technology changes the physical characteristics of fine-grained soils such as clay and topsoil.

Technology Cost

Project costs can vary widely. Material processing can range from $22 to $65 per ton. Mobilization can cost from $5000 to $40,000. Factors affecting cost include location, contaminant type, contaminant level, analytical procedures, soil moisture, soil type, contaminated soil volume, site elevation, prevailing or seasonal weather changes, and fuel costs (D10173V, p. 2). At the Kelly Air Force Base, the cost of remediating 20,000 tons of total petroleum hydrocarbon-contaminated soil was $30 per ton (D10173V, p. 10). At a garage in the city of Brooklyn Center, cleanup of 47 tons of soil was $27.24 per ton (D10173V, p. 15). The cost of cleanup of 156.46 tons of soil at the Morris Fish Hatchery was $36.50 per ton (D10173V, p. 20). Cleanup of 6.63 tons of soil for State Farm Insurance was $250 total (D10173V, p. 25).

Information Source

D10173V, VISITT 4.0, 1995

T0183

Cornell University

Halorespiration

Abstract

An antibiotic-resistant bacterium, *Dehalococcoides ethenogenes* strain 195, that Cornell University researchers isolated from sewage sludge, has been found to remove all the chlorine from organic solvents such as tetrachloroethene (PCE) and trichloroethene (TCE) by halorespiration to form ethene, an innocuous end product.

Many contaminated sites contain microorganisms that can break down chlorinated molecules. Most microorganisms, however, are not very efficient in the natural environment and only partially dechlorinate their substrates, converting them to *cis*-dichloroethene and then vinyl chloride, a known carcinogen

Natural reductive dehalogenation of chlorinated solvents occurs when the bacteria can use the solvents as electron acceptors to generate energy for growth, similar to the way oxygen is used by anaerobic organisms. In halorespiration, the chlorinated solvents are reduced through reductive dehalogenation, which is the removal of one or more chlorine atoms and their replacement with hydrogen.

This strain uses the carbon–chlorine bond as an electron acceptor and molecular hydrogen as its source of electrons. A number of other anaerobic microorganisms, particularly methane-producing bacteria, also use hydrogen as an electron source, but this bacterium uses it at a lower concentration than most of its competitors.

Through laboratory testing, it was also determined that this culture could reductively dechlorinate 1,2-dichloroethane and 1,2-dibromomethane to ethene.

Technology Cost
No available information.

T0184

CORPEX Technologies, Inc.

CORPEX Technology

Abstract
CORPEX™ Technologies, Inc., offers CORPEX™ technology for the decontamination of undesirable and toxic ions or radionuclides from contaminated surfaces and coatings. The vendor states that the process can operate as either a batch or semicontinuous process. The commercially available CORPEX technology uses patented, innovative chelation chemicals to control and recover radioactive and other types of hazardous metal ions from soils, concrete, steel, and other materials.

The solutions used in the decontamination process can be destroyed, resulting in greater than 99.99% destruction of all organics present. The destruction process precipitates the contaminants, and then removes them by filtration and ion exchange for further processing.

The vendor states that the technology is patented and commercially available.

The vendor claims that CORPEX chemicals are more effective than other existing chelants in removing heavy metals and radioactive metal ions because of their unique molecular structures and enhanced solubility in water. They are effective over a wide range of temperatures (from freezing to boiling) and variable pH (from 1 to 14). The chemicals can be oxidized after the cleaning process and no undesirable residues are left—only water, carbon dioxide, carbon monoxide, and nitrogen.

The vendor states that additional testing will be required prior to a full-scale deployment of the technology.

Technology Cost
In 1998, the CORPEX technology was evaluated by the U.S. Department of Energy (DOE) at the Hanford facility in Richland, Washington. The process solution cost $60/gal for a 55-gal purchased quantity. The DOE reported that CORPEX appeared to offer substantial cost savings compared with existing baseline technologies (D23002U, p. 2).

Information Source

D23002U, U.S. DOE, 1998

T0185

Corrpro Companies Incorporated

Electroremediation

Abstract
Electroremediation[SM] is a method for the in situ removal of heavy-metal and organic compounds from low-permeability soils by the application of direct-current electric fields. These fields induce the transport of water and contaminants to wells where they are pumped to the surface. Massachusetts Institute of Technology (MIT) developed the Electroremediation technology, which is commercially available through Corrpro Companies Incorporated.

The technology is best suited for the removal of water-soluble metals and organics. Organics that would most likely be mobilized by this process include aromatic compounds such as benzene, toluene, xylene, and phenolic compounds, as well as chlorinated solvents. Electrokinetic remediation is not a practical method of remediation for insoluble organics such as heavy hydrocarbons.

The technology has the advantage of having a high degree of control over flow direction because contaminants move along electrical gradients that are defined by the placement of electrodes. An additional advantage of electrokinetic remediation is its ability to remove liquids from fine-grained soils, and to remove contaminants even in tight or heterogeneous soils.

It may be difficult to estimate the time that will be required to remediate a site using this technology. Heterogeneities or anomalies in the soil will reduce removal efficiencies. Extreme pHs at the electrodes may inhibit the system's effectiveness. The electrokinetic remediation process is limited by the solubility of the contaminant, the desorption of the contaminants from the soil matrix, and reduction–oxidation changes induced by the electrode reactors. Electrokinetic remediation requires sufficient pore water to transmit the electrical charge. Targeted contaminant and other ionic compound concentrations effect the efficiency of the process. Rinsing of the cathode may be necessary to wash away sodium ions and hydroxyl ions generated by electrolysis.

Technology Cost
In 1996, the cost of using Electroremediation including ancillary treatment costs was estimated by the technology developer to be from $20 to $30 per ton (D112889, p. 1). The costs will vary based on the site's specific chemical and hydraulic properties. The initial and target contaminant concentrations, concentrations of nontarget ions, conductivity of the pore water, soil characteristics and moisture content, the quantity of waste, depth of contamination, residual waste handling and processing, site preparation requirements, and electricity and labor rates have a significant effect on the unit price (D19938G, pp. 16, 17).

Cost estimates for cleanup using electrokinetic remediation are highly dependent on the types and concentrations of contaminants and the extent of remediation desired (D14546K, p. 194).

Energy costs rise substantially with applied voltage. Costs were extrapolated from bench-scale experiments involving phenol conducted in 1993. Energy costs were estimated to be $0.53 per ton of effluent removed when 25 V were used, and $26.00 per ton when 500 V were used (D13050X, p. 290).

Information Sources

D112889, Probstein, 1996
D13050X, Shapiro and Probstein, 1993
D14546K, U.S. DOE, June 1995
D19938G, Interstate Technology and Regulatory Cooperation Work Group, 1997

T0186

Cosolvent Flushing — General

Abstract
Cosolvent flushing is an in situ technology that enhances the remediation of contaminated soils and groundwater by injecting water and a cosolvent such as alcohol (e.g., ethanol, methanol, and isopropyl) into a contaminated area. Research has shown that an organic cosolvent can also accelerate the movement of metals through a soil matrix. The alcohol causes both an increase in aqueous contaminant solubility and lowering of non-aqueous-phase liquid (NAPL)–water interfacial tension.

This technology, along with similar technologies such as surfactant flushing, was originally developed in the petroleum industry to improve hydrocarbon recovery. Its use in environmental applications such as aquifer remediation is relatively new, with most laboratory and field trials having been carried out during the past 8 years.

According to researchers, cosolvent flushing has the following potential advantages:

- Enhances the mobilization of residual NAPL phases.
- Increases the solubility of organic compounds.
- Reduces contaminant sorption, facilitating the transport of dissolved contaminants.
- Increases mass-transfer rates.
- Offers potentially dramatic reductions in the time required to remove contamination.

The mobilization of NAPL in response to cosolvent flooding can lead to a worsening of the extent of contamination at a site. In the case of dense, non-aqueous-phase liquid (DNAPL), any lowering of interfacial tension has the potential to vertically remobilize contaminants. It must also be recognized that elevated contaminant concentrations in groundwater will occur during a chemical flood, raising the short-term risk of exposure (D16070D, p. 4). In addition, the cosolvent should possess a different boiling point than that of water and the solute to ensure posttreatment separation of the different streams (D14172A, p. 233).

Technology Cost
The cost of implementing a cosolvent flood may vary dramatically from site to site depending on the ability to reuse injected chemicals, methods of waste disposal, and the amount of chemical that needs to be purchased per unit of mass removed. For typical waste sites having contamination limited to the upper 49 ft below ground surface (bgs), estimated costs range from \$0.57 million per acre to \$7.5 million per acre. These costs translate to a range of approximately \$65 to \$750/yd^3 of treated contaminated soil. Higher costs are generally associated with smaller sites, where no economies of scale can be realized, and with lower permeability or heterogenous soils where flushing needs to be carried out for longer periods of time (D16070D, p. 4).

One of the primary components in the cost of cosolvent flushing technology is the cost of the cosolvent solution. Reuse of the flushing solution has shown the potential to greatly reduce the cost of treatment by reducing both chemical costs and the treatment and disposal costs of the extracted contaminants (D21314Z, p. 5).

In 1998, a pilot-scale field demonstration of cosolvent flushing technology took place in Jacksonville, Florida. The cost of the demonstration was approximately \$440,000. Plans were in development for a full-scale application of the technology. It was estimated that alcohol reinjection could reduce the cost of treatment by up to 50% (D21314Z, p. 10).

Information Sources

D16070D, 1997
D21314Z, Strbak, 2000

T0187

Covenant Environmental Technologies, Inc.

Mobile Retort Unit

Abstract
The mobile retort unit is an ex situ thermal desorption technology that, in the absence of air, can remove hydrocarbons from contaminated soil or other media. The term “retort” means that the material is heated in the absence of air to vaporize the hydrocarbons, which are then transported to a condenser and collected, all in a closed system.

This technology is protected under U.S. Patent No. 5,205, 225. The commercial availability of this technology is uncertain.

The MRU technology is not applicable to heavy-metal-contaminated soils nor to radioactive waste contamination. The one exception to heavy-metals remediation is mercury. The vaporization temperature for mercury is well within the operating range of the MRU, and because of closed chamber construction, it is ideally suited for the removal and reclamation of mercury from contaminated soil.

The water content of the soil or other medium to be treated limits the amount of material that may be processed per hour. This does not influence the effectiveness of the MRU, only the rate of processing, and thus, the profitability.

Technology Cost
According to VISITT Version 4.0, the cost for this technology is $100 to $800 (1995 dollars) per ton of waste material treated. This estimate does not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals.

Factors that have a significant effect on unit price include the following:

- Characteristics of soil
- Waste handling/preprocessing
- Target contaminant concentration
- Moisture content of soil
- Characteristics of residual waste
- Amount of debris with waste
- Initial contaminant concentration
- Site preparation
- Depth to groundwater
- Depth to contamination
- Labor rates
- Utility/fuel rates
- Quantity of waste (D10171T, p. 19)

Information Source

D10171T, VISITT Version 4.0, 1995

T0188

Croy Dewatering & Environmental Services, Inc.

Dual-Phase Recovery Unit

Abstract
Croy Dewatering & Environmental Services, Inc. (Croy), has developed the dual-phase recovery unit for the extraction of groundwater and the removal of volatile organic compounds (VOCs)

from soil. The dual-phase extraction system extracts contaminated groundwater and soil vapor at the same time. The vendor states that this reduces the time required to remediate the site. The technology is commercially available for sale or lease and has been used at several commercial sites in Florida for the remediation of sites contaminated with gasoline and solvents.

Croy states that its dual extraction technology offers the following advantages:

- Simple skid-mounted design.
- Quiet pump operation.
- Remediates contaminants in the smear zone between the water table and the overlying dry soil, resulting in faster site remediation.
- Because the pumps are not submerged in liquid and have only one moving part, the system is rugged and reliable.

Technology Cost

The Croy "V" series belt-driven dual extraction pump can extract from 5 to 30/gal min of liquid, and uses a 75 actual cubic feet per minute groundwater/vapor extraction transfer pump. The unit has a purchase price of $13,000 and can be rented for $1300 per month (D17804V, p. 11).

The Croy "E" series direct-drive dual extraction pump can be adjusted to pump from 5 to 60 gal/min during fluid transfer, and 500 actual cubic feet per minute during ground water/vapor extraction. The unit can be purchased for $20,000 and rents for $2000 per month. All units can be trailer mounted for mobility. Trailer costs are dependent on system size, number of axles required for transport, and other factors (D17804V, p. 17).

Croy manufactures a series of SFR pumps that are also for sale (D17804V, p. 6–10). Croy offers a three-cylinder, diesel-driven dual-phase extraction unit that can be leased for pilot tests. As of 1998, the unit rented for $1200 per week, and its purchase price was $20,750 (D17804V, p. 21).

Information Source

D17804V, Croy Dewatering & Environmental Services, Inc., undated vendor literature

T0189

CryoGenesis

Cryogenesis Surface Decontamination System

Abstract

CryoGenesis offers the Cryogenesis® surface decontamination system for use in cleaning and decontamination of surfaces contaminated with hazardous and radioactive materials. The technology uses pressurized dry ice pellets that impact the surface and undergo sublimation (direct phase change from solid to gas). This serves to break the bond between the contaminants and the surface, lifting them off where they can be removed by the pressurized spray. The airborne contaminants are then removed by an air filtration system, and the larger particles are collected in a treatment chamber. The technology is commercially available.

CryoGenesis claims the Cryogenesis system offers the following advantages over other decontamination and cleaning technologies:

- System is cheaper.
- Generates no secondary wastes.
- Safe for employees, machinery, and the environment.

- Allows for automation using robots.
- Is compact and easily portable.

Performance of the unit has proven to be dependent on the level of decontamination required and on the type of coating covering the decontamination. Wastes recovered by this process may require additional treatment or disposal as radioactive, mixed, or hazardous wastes.

Technology Cost

Cryogenesis machinery can be purchased directly from the vendor. According to information supplied by the vendor in 1997, accelerator costs range from \$16,250 to \$25,000. Pellitizer costs range from \$39,500 to \$72,000 (personal communication: James Becker, President, CryoGenesis, 1997).

According to information supplied by the vendor in 1996, the dry ice pellets used in the Cryogenesis system cost between 15 and 30 cents per pound. The system uses from 100 to 150 lb of pellets per hour. More dry ice is required for paint stripping applications, and less for oil film and clinging dirt removal (D15397T).

The standard accelerator is the Model 1350-3. This unit comes with blasting hoses and one standard ice gun and costs \$20,500. The Model 1350-3A has a control system that allows for particle sizes from $\frac{1}{8}$ inch to 100 μm in diameter (personal communication: James Becker, President, CryoGenesis, 1997).

The standard Pellitizer is the Model 250. This unit costs \$39,500, has a 7.5 horsepower motor, and can manufacture 250 lb of pellets per hour. The Model 650 costs \$55,000, has a 20-horsepower motor, and has a capacity of 650 lb of pellets per hour. The Model 1000 costs \$72,000, operates using a 20-horsepower motor, and has a capacity of 1000 lb of pellets per hour (personal communication: James Becker, President, CryoGenesis, 1997).

Information Source

D15397T, CryoGenesis, 1996

T0190

Cunningham-Davis Environmental (CDE Resources, Inc.)

CDE Soil Recycling

Abstract

Cunningham-Davis Environmental (CDE) has developed a technology for ambient temperature recycling of petroleum hydrocarbon-, metal-, and creosote-contaminated soils and sludges. After ex situ remediation with proprietary emulsions and reagents, the soils and sludges are recycled into construction-grade products, such as base, pavement, engineered fill, landfill liners, and caps. This technology is commercially available.

The characteristics of a soil determines the cost-effectiveness of the recycled product. Sandy, silty, and cobble soils are more suitable for recycling into asphalt concrete.

Conversely, clay-rich soils are most effectively recycled into a low-permeability liner. Soil or rock aggregate can be used to supplement soils as needed. All information is from the vendor and has not been independently verified.

Technology Cost

According to the vendor, the cost to remediate 15,000 tons of soil and construct 16,150 ft of road with it would be \$1,100,000. The cost of building a conventional road 16,150 ft long would be \$700,000 (D16398Y).

Information Source

D16398Y, vendor literature

T0191

Cunningham-Davis Environmental (CDE Resources, Inc.)

ID-20 Chemical Neutralization Process

Abstract

The ID-20 chemical neutralization process is an ambient temperature process that includes the ex situ mixing of soils and sludges in a high-capacity pug mill system with a proprietary reagent to reduce the organic contamination through nitrification and subsequent biodegradation. This technology is commercially available. All information is from the vendor and has not been independently verified.

Technology Cost

No available information.

T0192

Cure International, Inc.

CURE Electrocoagulation Wastewater Treatment System

Abstract

The Cure International CURE electrocoagulation system is a patented, ex situ technology that operates by first precipitating or coagulating dissolved ions and suspended charged particles from wastewaters and then removing the solids by physical means such as filtration. Because many toxic metal ions, such as nickel, lead, and chromates, are held in solution by electrical charges, they will precipitate out of solution if they are neutralized with oppositely charged ions. The CURE system uses electrochemically generated ions to precipitate ions, flocculate colloidal particles (clays and high-molecular-weight organics such as oils), and, with a clarifier, filter, and/or centrifuge, remove the suspended solids. The system improves upon previous electrocoagulation methods through a unique concentric arrangement of the electrodes allowing continuous and consistent treatment of wastewater with even passage of electrical current through the fluid.

CURE can be used to remove a broad range of both organic and inorganic contaminants, including bacteria and dissolved metals such as aluminum, arsenic, barium, cadmium, chromium, cyanide, lead, nickel, uranium, and zinc. Because electrocoagulation can remove other suspended materials from solution, this technology can treat mining, electroplating, and industrial wastewaters as well as contaminated groundwater. The system can also pretreat water for reverse osmosis systems since it reduces silica, calcium, and suspended solids.

An advantage of the CURE process is the ability to achieve high contaminant removal rates. Also, floc, a by-product of the CURE process, tends to be stable and settle rapidly. Electrocoagulation will not remove metals that do not form precipitates. In addition, electrocoagulation will not remove nonreactive, soluble organic compounds nor desalinate water.

According to information from the vendor received in September 1999, the company is closed for business and CURE is no longer available.

TABLE 1 Capital Costs for CURE Electrocoagulation Systems

System Size	Cost to End User		
(gal/min)	Simple	Moderate	Sophisticated
1.0–5	$35,000	$75,000	$125,000
10–20	$75,000	$125,000	$150,000
25–40	$125,000	$150,000	$225,000
50–75	$150,000	$225,000	$330,000
80–100	$225,000	$300,000	$500,000
120–150	$300,000	$400,000	$600,000
160–200	$400,000	$600,000	$750,000
220–250	$600,000	$750,000	$1,000,000

Source: Adapted from D14357H, Cure International, Inc., Statement of Qualifications.

Technology Cost

According to the vendor, system capital costs for the CURE system can range from $35,000 for a small, simple system to $1,000,000 for a large, sophisticated system. Additional vendor cost estimates are listed in Table 1. These estimates do not include the cost of a clarifier for the CURE system or the cost of sludge handling (D14357H).

At a municipal treatment plant near Denison, Texas, the costs of treating wastewater using CURE are $0.241 per 1000 gal. This plant has an average daily flow of 1,000,000 gal. A new CURE system installed at a manufacturing plant in Denton, Texas, costs approximately $0.055/gal to operate. The manufacturing plant processes approximately 30,000 gal of wastewater per day (D14357H).

The U.S. Environmental Protection Agency (EPA) calculated operating costs for CURE based on remediation efforts performed at the U.S. Department of Energy's Rocky Flats Environmental Technology Site near Golden, Colorado. The EPA estimated that remediation costs for a 100-gal/min CURE system could range form $0.003 to $0.009/gal, depending on the duration of the remedial action (D205163, p. iv).

The U.S. Coast Guard used a CURE system to treat 176,000 liters of ship bilgewater at Kodiak Island, Alaska. The treatment costs, which included labor, equipment, and energy, were determined to be less than $0.12/liter These costs represent 10% of the costs associated with transporting and treating wastewaters off of the island (D14378M).

Information Sources

D14357H, Cure International Inc., date unknown

D14378M, Woytowich et al., date unknown

D205163, U.S. EPA, 1998

T0193

Current Environmental Solutions, L.L.C.

In Situ Corona

Abstract

Current Environmental Solutions, L.L.C. is developing in situ corona (ISC) technology as an in-place method for remediating organic compounds in soils. Pilot-scale experiments have shown

TABLE 1 Projected Treatment Costs for In Situ Corona

Cost Element	Cost per Site	Cost per Cubic Meter
Energy	$22,700	$14.50
Setup and operation	$45,900	$29.00
Engineering	$9,200	$6.00
Electrodes	$41,000	$26.00
Equipment	$22,400	$14.00
Contingency (25%)	$35,300	$22.50
Total	$176,500	$112.00

Source: Heath et al., 1994 (D116405).

that ISC has the potential to destroy organic compounds, chlorinated organics, and chlorofluorocarbons. Tests indicate ISC provides uniform soil treatment at levels that exceeded evaluation objectives. ISC uses a high-energy plasma to produce gas-phase oxidants, capable of oxidizing contaminants in the treatment medium. ISC technology has been applied to soils and liquids, while a related technology, a gas-phase corona reactor (GPCR), has been applied to soil off-gases. ISC has been combined with another technology developed at Pacific Northwest National Laboratory (PNNL), six-phase soil heating, to form a technology called electrical remediation at contaminated environments (ERACE). ISC has not been field tested.

The performance of ISC units is affected by soil type and soil moisture content. Waste streams derived from ISC processing may consist of volatile off-gases formed during oxidation reactions and products of incomplete oxidation. Bench-scale studies have shown that volatile residuals can be created by ISC, but they have, as yet, not been fully characterized.

Technology Cost

In 1994, following pilot-scale studies on in situ corona (ISC), Pacific Northwest Laboratories (PNNL) estimated that the total costs for ISC would be $\$112/m^3$ of soil treated. This estimate is based on the treatment of four sites per year, with each site having a soil volume to be treated of 1570 m^3, a treatment depth averaging 10 m, and an initial moisture content of 15% (D116405, p. 816). Results are summarized in Table 1.

Information Sources

D116405, Heath et al., 1994

D13472F, U.S. DOE, 1995

T0194

Current Environmental Solutions, L.L.C.

Six-Phase Soil Heating

Abstract

Six-phase soil heating (SPSH—formerly known as ERACE) is an in situ thermal technology that enhances the removal of volatile and semivolatile organics during soil vapor extraction (SVE). It may be used in applications involving soils with low permeability, low contaminant volatility, or high water content. SPSH uses low-frequency electricity delivered to six electrodes

in a circular array to heat soils internally as an enhancement to SVE. Electrical heating also provides an in situ source of steam to accelerate further removal of volatile organics from soils. This enables less volatile, higher-molecular-weight compounds to be removed by simple venting. Volatilized contaminants are sent to a catalytic oxidation system for destruction, or the contaminants can be condensed out and treated as liquids.

SPSH has received multiple patents and has been used in full-scale remediations. It is commercially available in the United States through Current Environmental Solutions L.L.C., (CES), which was established by, and is supported by, staff and equipment from Battelle and Terra Vac Corp. Current Environmental Solutions also offers the technology in select markets in Europe and Asia.

SPSH has several advantages. It is applicable to sites where contaminants are present as non-aqueous-phase liquids (NAPLs). The technology reduces volatile organic carbon (VOC) removal time to a few weeks for a typical site, whereas soil vapor extraction (SVE) alone requires years for remediation. This reduction in removal time can significantly decrease costs over SVE (from 2 to 10 times). Excavation and ex situ soil treatment is typically much more expensive to implement than SPSH, especially at deep sites.

The in situ nature of this treatment also minimizes potential exposure to humans and the environment. Ex situ options like excavation require repeated worker handling of the contaminated soil and increased opportunity for volatilization of contaminants (leading to off-site contamination). The off-gas stream generated as part of the SPSH process can be treated using conventional off-gas treatment technologies such as catalytic oxidation, thermal oxidation, condensation, and granular activated carbon (GAC).

SPSH has several potential limitations. The site geology must be amenable to the installation of electrodes. The presence of underground pipes or utilities, buried metal debris, or other conductive objects may present a safety hazard. There is also no established treatment depth limit, but it is generally accepted that SPSH can treat the top of the water table. In addition, this technology may not be effective at sites with highly saturated soils.

Technology Cost

Based on data from a demonstration at the Savannah River site, the total cost for SPSH was estimated to be $86/yd^3$. In contrast, the use of traditional SVE at the site would have cost an estimated $576/yd^3$. Total capital cost for the Savannah River site demonstration was estimated to be $1,277,300. Total operation and maintenance cost was estimated to be $16,900 per month. Table 1 gives a cost comparison between SPSH and SVE (D105759, pp. 15,16; D222606, p. 232). Detailed breakouts of capital cost as well as operation and maintenance cost can be found in Case Study 2.

Energy consumption is an important factor in considering the economic feasibility of SPSH technology. During the SRS demonstration, 100,000 kWh of energy was applied to an estimated 1100 m^3 of soil (heated above 70°C). The calculated energy consumption is $7/$m^3$ at $0.07/kWh.

TABLE 1 Cost Comparison for Six-Phase Soil Heating and Soil Vapor Extraction

Technology	Cleanup Duration (year)	Amortized Total Cost[a] (Million Dollars)	Total Volume Remediated[b] (Cubic Yards)	Total Cost (Dollars per Cubic Yard)
Six-phase soil heating	5	2.724	785,000	86
Soil vapor extraction	50	33.358	785,000	576

Source: Adapted from D105759.
[a]Total cost (capital and operation and maintenance) is amortized with a discount rate of 2.5%.
[b]1 cubic yard equals 0.765 cubic meter.

The energy cost to heat the soil is small when compared to capital equipment costs and operator time (D105759, p. 15).

According to the vendor in 1998, treatment costs were estimated to generally range from $40 to $80/yd^3 of contaminated soil treated. Treatment costs vary according to site geometry, soil type, and contaminant(s) treated (D19004F, p. 2). In 1999, the vendor stated that achieving a 99% contaminant reduction costs approximately $1,000,000, plus $30/yd^3 of soil treated. Using this estimate, the technology is more cost effective at sites that are more than 1500 yd^3 in size. Electricity costs make up about 25% of total treatment costs. Heating the vadose zone costs approximately $7.5/yd^3, while treating aquifers costs $8.4/yd^3 (D203816, p. 8).

For a project at Fort Richardson in Alaska, total treatment costs using SVE and SPSH were $967,822. Costs ranged from $189 to $288/yd^3 of soil treated, or $726 to $2552/lb of contaminant removed. Because the site was in a remote location, diesel generators were used as a power source. This factor may have increased treatment costs (D21202S, pp. 34, 35). For additional information about this project, please see Case Study 3.

At a former manufacturing facility in Skokie, Illinois, the initial phase of treatment required 1775 MWh of electrical energy purchased at a base rate of $14,000 per month, plus a use rate of $40/MWh. Total electrical costs for the initial phase were $148,000, or approximately $6.41/m^3 of treatment volume (D19290Z, p. 2). According to the vendor, the full-scale application of the technology at this site cost approximately $32/yd^3 of soil treated (D18968I, p. 6). For additional information, see Case Study 4.

The vendor stated in 1999 that treatment costs for a six-phase system typically range from $25 and $75/yd^3 of soil treated, including electrical power usage (D19509Z, p. 10).

Information Sources

D105759, U.S., DOE, 1996.

D19509Z, Current Environmental Solutions, L.L.C., 1999

D19290Z, Current Environmental Solutions, L.L.C., 1999

D18968I, Current Environmental Solutions, L.L.C., Undated

D19004F, U.S. DOE, 1998

D203816, U.S. EPA, 1999

D21202S, U.S. EPA, 2000

D21942L, U.S. EPA, undated

D222606, National Academy Press, 2000

T0195

DAHL & Associates, Inc.

ThermNet Radio Frequency Heating

Abstract

The ThermNet^{SM} technology uses electromagnetic energy in the radio frequency (RF) band to heat soil. The technology is used to enhance the in situ removal of volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and straight-chain and polycyclic aromatic hydrocarbons. The technology can be used with SVE technologies or as an aid in bioremediation.

This technology was developed through a joint effort between KAI Technologies, Inc., of Portsmouth, New Hampshire, and DAHL & Associates, Inc., of St. Paul, Minnesota. The two companies are working to develop applications of ThermNet throughout North America. DAHL & Associates, Inc., markets the technology. ThermNet^{SM} has been used in full-scale cleanups and is commercially available.

The vendor list the following advantages of the ThermNet system:

- Offers several flexible antenna systems to heat the soil.
- Provides mobile systems with modular components that can be designed to match site requirements.
- Achieves over 90% efficiency in coupling the energy to the soil.
- Treats a variety of contaminants in both the vadose and phreatic zones.

The technology cannot be used if large metal objects are buried in the treatment zone. In general, ThermNet technology is not recommended for the remediation of saturated soils. If saturated soil is to be remediated by radio frequency heat (RFH), the treatment zone should be dewatered prior to treatment. The technology can only be used to remove contaminants that can be volatilized at soil temperatures that the system can practically achieve throughout the treatment zone. Contaminants in silty or clayey soils are usually strongly sorbed and are difficult to remove.

Technology Cost
The cost of the ThermNet technology and SVE remediation was estimated to be approximately $336 per ton of soil treated based on data from the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration of KAI's RFH technology. The demonstration was held at Kelly Air Force Base in San Antonio, Texas, from January through July 1994 (D11020J, pp. 33–34).

The SITE cost estimate was based on the following parameters:

- Equipment
- Startup and fixed
- Operating costs for treatment
- Supplies
- Consumables
- Facility modification, repair, and replacement and site demobilization (D11020J, p. 34)

Costs were estimated for treatment of 10,940 tons of soil with an process on-line efficiency of 95% (D11020J, p. 33). Approximately $50 per ton of the total cost was attributed to the SVE system (D11020J, p. 34). The estimate did not include costs associated with analyses, site preparation, permitting, effluent and disposal, or residuals and waste shipping, which were considered site-specific costs (D10505V, p. 6).

Information Sources

D11020J, U.S. EPA, 1995
D10505V, U.S. EPA, 1995

T0196

Dames and Moore

Bioinfiltration

Abstract
Dames and Moore has developed bioinfiltration technology that combines in situ bioremediation of soils with ex situ bioremediation of groundwater. The vendor states that the technology

can treat soil, natural sediment, and groundwater contaminated with hydrocarbons, phenols, chlorinated compounds, or alcohols.

In bioinfiltration, groundwater is pumped through an above-ground biological process train, and the treated groundwater is reinjected through an infiltration gallery found within the contaminated soil zone (in situ bioremediation). The ex situ biological process train consists of a submerged fixed-film bioreactor, aeration, nutrient control, pH control, solids removal/control, and reinjection pumps.

The vendor states that bioinfiltration can provide a greater area of lateral influence as compared to some other bioremediation systems. The application of any required nutrient is simplified as it is possible to add them to the treated effluent prior to reinjection.

Bioinfiltration is limited by the ability of soil microorganisms to degrade the contaminants of concern, since bacteria cannot metabolize or co-metabolize contaminants at toxic concentrations. Indigenous microbial populations require sufficient time to adapt to contaminants.

All information is supplied by the vendor and has not been independently verified.

Technology Cost

According to information provided by the vendor in 1996, typical treatment costs for bioinfiltration technology range from \$50 to \$100/yd^3 of material treated, based on 1000 or more cubic yards of treated material. Costs are depended on the area of impaction, the contaminant(s) treated, and the time constraints for treatment (D15646R, p. 2).

Other factors that impact treatment costs include:

- Waste quantity
- Initial contaminant concentration
- Target contaminant concentration
- Depth to groundwater
- Depth of contamination
- soil characteristics (D15646R, p. 13)

The vendor states that bioinfiltration technology was used at a gasoline service station in New Jersey to remediate soil and groundwater contaminated with fuel oil. The technology treated 2000 yd^3 of soil as well as the contaminated groundwater. The depth of contamination ranged from 8 to 12 ft. The total project cost was \$125,000 (D15646R, pp. 8–11).

Information Source

D15646R, VISITT 5.0

T0197

Dames and Moore

Two-Phase Vacuum Extraction

Abstract

The two-phase vacuum extraction (TPVE) technology allows for the in situ remediation of soils and groundwater contaminated with volatile organic compounds (VOCs). Two-phase vacuum extraction is similar to conventional vapor extraction in the equipment required, with the exception that it is designed to actively remove contaminated groundwater from the extraction well along with the vapor-phase contamination.

According to the vendor, the TPVE technology is currently commercially available.

Advantages of the TPVE technology include its ability to do the following:

- Cause minimal disruption to facility operations.
- Remove VOCs from the vadose zone.
- Possibly lessen the time required to remediate a site.
- Simultaneously remediate VOC-contaminated soil and groundwater.

This technology is most advantageous in low-permeability soils, such as clay, where only a limited amount of groundwater can be withdrawn by traditional pumping methods.

The TPVE technology is not applicable to the in situ recovery of metals. Dissolved metals, however, can be recovered with the extracted groundwater and treated appropriately.

If this technology is not combined with complementary technologies such as bioremediation or air sparging, it is not applicable to heavier organics such as long-chain hydrocarbons or complex contaminants such as heavy fuels that contain compounds with low vapor pressure.

This technology needs to be combined with complementary technologies such as pump and treat to recover groundwater from high-yielding aquifers.

Freeze protection is required in cold climates.

Technology Cost

The estimated price range is $20 to $75 per ton. These estimates do not always include all indirect cost associated with treatment such as excavation, permits, and treatment of residuals. Factors that have a significant effect on the unit price of this technology include the following:

- Initial contaminant concentration
- Target contaminant concentration
- Depth of contamination
- Depth to groundwater
- Amount of debris with waste
- Characteristics of soil (D13088B, p. 22)

According to the vendor, the capital costs for the treatment system include a 200-actual cubic-feet-per-minute (ACFM) vacuum pump, two transfer pumps, a carbon steel knockout pot, and associated instrumentation and piping. Operation and maintenance costs for the system include estimates for additional granular activated carbon (GAC) units, liquid- and vapor-phase analysis, weekly monitoring, electricity, and routine maintenance. These costs vary, depending on the monitoring requirements, contaminant concentrations, and other variables (D13124Y, p. 492).

Information Sources

D13124Y, Lindhult and Tarsavage, 1993

D13088B, VISITT Version 5.0, 1996

T0198

Davis Environmental

Multistage In-Well Aerator

Abstract

The multistage in-well aerator is an inexpensive, low-maintenance device that simultaneously treats and extracts contaminated groundwater using only compressed air. Air stripping is based

on the propensity of volatile organic compounds (VOCs) to move from higher concentrations in water to lower concentrations in air until chemical equilibrium is established between the two phases. Removal of VOCs from water by air stripping is best accomplished by maximizing the air/water surface area interface and passing a continuous stream of clean air by the water until the VOCs are removed to the desired level. The aerator uses concentric pipes in two sections of the well to redirect water flow through multiple in-well aerators during pumping. The off-gas is discharged directly to the atmosphere or can be collected, if necessary.

The technology was successfully demonstrated at a University of California at Davis site. The demonstration was an in situ treatment of groundwater contaminated with chloroform, carbon tetrachloride, Freon-12, and 1,2-dichloroethane. More than 100 million gallons of groundwater have been treated since October 1995 at this site. This technology is commercially available.

The vendor claims the following advantages of the Multistage in-well aerator:

- Simple and inexpensive method of removing VOCs from groundwater
- One-pass system for complete removal of VOCs
- Ease of installation and removal
- Low maintenance and little biological or chemical fouling of equipment
- Applicable in any geologic matrix and does not require special well construction
- Treatment can be in situ or ex situ
- Pilot tests are inexpensive
- Discharge from each well can be routed individually

The multistage in-well aerator system may not be cost effective with sites that have high yielding wells (greater than 60 gal/min), low-volatility VOCs, or requirements for nondetect effluent levels.

Technology Cost

According to the vendor, the cost of the multistage in-well aerator system is 50 to 75% of the cost expected for a conventional air stripping system using stacked trays or packed towers. The University of California (UC) at Davis landfill groundwater cleanup system costs under \$200,000, compared with quotes of \$401,000 for a packed-tower system and \$326,000 for a stacked-tray system. See Table 1 for a detailed comparison of the multistage in-well aerator and conventional air strippers. According to the vendor, cost savings are due to the following

TABLE 1 Multistage In-Well Aerator vs. Conventional Air Strippers

Item	Multistage In-Well Aerator (\$)	Actual Low Bid Stacked Tray (\$)	Feasibility Study Estimates (\$)
Aquifer pump test/extraction well layout	57,000	57,000	50,000
Extraction wells	45,000	45,000	25,000
Main system component and housing	21,000	100,000	184,000
Power (main panel and extraction wells)	6,000	46,000	33,000
In-well components	8,000	28,000	18,000
Water discharge piping	10,000	50,000	221,000
Engineering and installation	50,000	included above	149,000
Total	197,000	326,000	680,000
Savings with aerator		129,000(40%)	483,000(71%)

Source: Adapted from D17088R.

features of the multistage in-well aerator system: air compressor, as opposed to air stripper; power distribution to wells; aerators, as opposed to electrical pumps; and water discharge piping (F17088R, pp. i, 16, 17).

Pilot testing should cost less than $10,000 including analysis fees if an extraction or test well of at least 6 inches in diameter is available. Annual operation and maintenance costs for the existing system have been about $1750 for quarterly maintenance of the air compressor. All estimates are in 1996 dollars. In addition, about 40 hr of staff time has been used for routine inspections of the system (D148930, p. 4).

The total cost of the multistage in-well aerator installed at UC Davis was approximately $200,000. This included $147,000 for aquifer pumping tests and well installation and an estimated $50,000 for aerator design engineering and labor. According to the vendor, the components of a typical 8-inch diameter by 106-ft-deep well using a multistage in-well aerator, cost approximately $2565 (D17090L). Annual system operational costs for the full-scale commercial at UC Davis has been cited by the vendor to cost about $13,800, and maintenance costs are approximately $1650. The maintenance cost included quarterly oil and air filter change for the air compressor and an in-depth maintenance inspection, but did not include staff support expenses, which the vendor claims would be minimal (D17088R, p. 16).

Information Sources

D148930, Davis Environmental, undated vendor literature
D17090L, Davis Environmental, undated vendor literature
D17088R, Davis Environmental, 1997

T0199

Dehydro-Tech Corporation

Carver-Greenfield Process

Abstract
The Carver-Greenfield® process (C-G process) is a patented drying and solvent extraction process designed to separate oil-soluble contaminants from liquid, solid, or slurry wastes. The process has been used extensively over the last 30 years to dry and extract compounds from a variety of wet, oily solids in various industries. C-G process units may consist of modular designs or custom made for large-capacity operations.

The C-G process is no longer offered commercially. Rather, it has been replaced by an improved, second-generation version called the Biotherm Process™ offered by American Biotherm, L.L.C.

By-products of this process consist of three components:

- Dry solids with low percentages of water, indigenous oil, or carrier oil
- Water with very low percentages of solids, indigenous oil, or carrier oil
- Soluble compounds

The C-G process has been tested on the demonstration level by the U.S. Environmental Protection Agency (EPA). Studies have also been carried out for treating petroleum refinery wastes using this technology. It has been applied on a large scale to dry municipal sewage treatment solids.

Dehydro-Tech Corporation (DTC) lists the following advantages of the C-G process: reliable; easy to operate and install; proven in over 80 installations worldwide; produces water requiring

minimal treatment; requires 5 to 10 times less energy than alternative systems; works on feed materials containing any amount of water; destroys bacteria, viruses, and other pathogens; and requires minimum space.

The C-G process does not destroy wastes but rather separates mixtures into streams that may be more easily disposed of or treated. The process does not treat metals. All three streams emerging from the C-G process as treated wastes may require further processing prior to disposal.

See also American Biotherm, L.L.C., Biotherm Process™ (T0034).

Technology Cost

The Carver-Greenfield (C-G) process is no longer offered commercially. Rather, it has been replaced by an improved, second-generation version called the Biotherm Process offered by Biotherm, L.L.C. *See also* Biotherm, L.L.C., Biotherm Process™ (T0034).

An analysis of technology costs for the C-G process was included in a report published by the U. S. (EPA) in 1992. The cost estimate for treating petroleum-contaminated drilling mud waste is extrapolated from test results obtained in EPA laboratory tests. The estimate assumes treatment of 23,000 tons (21,000 metric tons) at a rate of 1.4 tons (1.3 metric tons) per hour. The EPA per ton cost estimate is $523. Of this amount, C-G process-specific cost was $221 and site-specific cost was $302. Of the site-specific costs, $240 was for incinerating the recovered oil. Costs presented in this analysis were reported as order-of-magnitude estimates (i.e., −30 to +50%). Other assumptions used in this estimate are included in Case Study 1 (D105453).

DehydroTech Corporation (DTC) offers the following cost summary for the C-G process. For the processing of 1.4 tons (1.3 metric tons) of petroleum-contaminated drilling mud wastes per hour, with the total amount of wastes processed as 23,000 tons (21,000 metric tons), DTC estimates that C-G process-specific costs per ton range from approximately $117 to $200 (D11043Q, p. 788). DTC claims that site-specific costs can range from less than $10 per ton to over $300 per ton (D105453, p. 28). DTC notes that in some applications, recovered wastes may be economically viable, thus lowering total cost.

According to DTC, typical operating costs range from $50 to $100 per feed ton (0.91 metric tons) for refinery-type wastes, and $100 to $200 per feed ton for soil remediation. DTC notes that estimates are feed and product quality sensitive and site specific. Remediation of polychlorinated biphenyl (PCB)-contaminated soil must also take into account the cost of destroying the concentrated PCB product (D11041O, p. 7).

Four C-G process plants using the "light solvent" process for the drying of municipal sewage sludge have been constructed. The two plants that were opened experienced a variety of problems with plant design and dewatering requirements. One plant was closed due to high processing costs (D11044R, p. 3).

Information Sources

D105453, U.S. EPA, August 1992, SITE Applications Analysis Report

D11041O, Trowbridge and Holcombe, 1993

D11044R, Holcombe, 1995

T0200

Delphi Research, Inc.

DETOX

Abstract

Delphi Research, Inc., has developed DETOX℠ technology for the moderate-temperature (150 to 200°C), low-pressure [20 to 200 pounds per square inch gauge (psig) (140 to 1400 kP)]

treatment of hazardous wastes. DETOX technology is an ex situ catalytic wet oxidation process using iron(III) as the primary oxidant. According to the vendor, the technology can be used on liquids, solids, and sludges. The technology oxidizes organic compounds and dissolves metals. DETOX technology could potentially be operated in continuous, semicontinuous, or batch mode. The technology has been evaluated in bench- and laboratory-scale experiments. In 1997, it was reported that Delphi had developed a business plan for commercialization and deployment of DETOX technology.

According to the vendor, DETOX has the following advantages:

- Accepts a wide variety of waste streams and sizes.
- Produces no nitrogen oxides, sulfur oxides, dioxins, or furans.
- Operates at moderate temperature and near atmospheric pressure.
- Contains and concentrates heavy metals and radionuclides.

DETOX will not oxidize highly resistant organic compounds such as Teflon™. Process solution and process vapors are corrosive. The solution is oxidizing in nature; the vapors are reducing. Wastes containing significant fractions of nontoxic inorganic materials that are soluble in the process solution (e.g., limestone) may not be suitable for treatment. Wastes with large amounts of sulfides or cyanides may not be suitable for treatment, as they would produce hydrogen sulfide or hydrogen cyanide vapors, respectively, during DETOX processing.

Technology Cost

Delphi Research, Inc. (Delphi), estimates the capital cost of a 50-gal (190-liter) reactor capable of processing 10 to 50 lb (4.5 to 23 kg) of waste per hour at $100,000 to $200,000. The capital cost of a permanent facility with a 5000-gal (19,000-liter) reactor capable of processing 100 to 500 lb (45 to 230 kg) of waste per hour would be $2 to $4 million. Based on a scale-up of bench-scale results, Delphi estimated that operating costs for DETOX technology would range between $150 and $1500/ton ($165 to $1650/metric ton) of organic wastes processed (D123728, p. 2).

In 1996, Delphi estimated the cost of processing wastes at $2.50 to $10.00/kg. Among the factors listed as affecting cost were quantity of waste, labor rates, initial contaminant concentration, characteristics of residual waste, waste handling and pretreatment, amount of debris, utility/fuel rates, and target contaminant concentration (D13821G, p. 24).

Information Sources

D123728, Dhooge, Delphi Research, Inc.
D13821G, VISITT 5.0, 1996

T0201

Delta Cooling Towers, Inc.

Aqua-Trim and VANGUARD Air Strippers

Abstract

Delta Cooling Towers, Inc. (Delta), has designed and manufactured two complete air stripper systems: VANGUARD® and Aqua-Trim™. The air strippers use a countercurrent, forced-draft design to remove volatile organic chemicals and certain other substances from water. While the VANGUARD air stripper is commercially available, Delta has stopped making the Aqua-Trim stripper.

The technology developer claims that the air strippers can treat volatile organic compounds (VOCs), such as benzene, toluene, and xylenes. According to the developer, the technology can also treat organic solvents, chlorinated hydrocarbons, fuel/gasoline hydrocarbons, and degreasers.

The developer claims that the cost effectiveness of the technology with respect to initial, operating, and maintenance costs makes it a preferred water remediation technology.

Technology Cost
No available information.

T0202

Detox Industries, Inc.

DETOX Process

Abstract
The DETOX process is primarily an in situ biodegradation process. The technology consists of two key elements: (1) nonpathogenic and nongenetically engineered microorganisms that can biologically destroy refractory and nonrefractory organic chemicals; and (2) controlled introduction of water, nutrients, oxygen, microorganisms, soil conditioners, pH adjusters, and surfactants into all types of soils.

The process destroys such refractory chemicals as polychlorinated biphenyls (PCBs); pentachlorophenol (PCP); polynuclear aromatic hydrocarbons (PAHs); benzene, toluene, ethylbenzene, and xylene (BTEX); creosote; phenolics; and pesticides. DETOX also destroys less refractory chemicals, such as unrefined and refined petroleum hydrocarbons.

The process is applicable to sludges, sediments, and liquids and to in situ soil remediation.

The DETOX process operates most effectively at soil temperatures between 60 and 95°F (16 and 35°C). The bioremediation process stops at soil temperatures below 32°F (0°C) and at soil temperatures above about 140°F (60°C).

Because the biodegradation process destroys the contaminants, liabilities associated with nondestructive processes are eliminated.

The DETOX process is no longer offered commercially by the developer, who filed for bankruptcy in 1996.

Technology Cost
The treatment costs using the DETOX process are substantially lower than those using traditional technologies such as incineration, landfill disposal, and alternative destructive technologies. Treatment costs for the process are equivalent to or less costly than nondestructive technologies such as encapsulation (D10163T, p. 2).

Information Source

D10163T, VISITT 4.0

T0203

Dissolved Air Flotation — General

Abstract
Dissolved air flotation (DAF) is a commercially available, ex situ technology for the treatment of groundwater, process water, and wastewater contaminated with petroleum hydrocarbons. The

technology involves the introduction of air or other gases under pressure to form bubbles. Suspended oil emulsions adhere to the minute gas bubbles and rise to the surface where they can be more easily removed.

Technology Cost
No available information.

T0204

Thermal Distillation — General

Abstract
Thermal distillation is a process that uses heat to volatilize hydrocarbons and water from contaminated media. The volatiles are later condensed and separated, leaving only reduced-volume solids suitable for landfilling.

The process recovers hydrocarbons suitable for reuse or recycling and recovers water treatable in wastewater treatment facilities. Thermal distillation can be used for waste minimization, recycling, or as a final treatment.

Thermal distillation can be used to treat almost any type of hazardous organic waste, whether it is continuously generated or has been impounded for several years. It can be used to treat liquids, sludges, sediments, or soils. Units can be designed for fixed sites or for mobility.

The most common use of thermal distillation is in the petroleum industry, where it can be used for American Petroleum Institute (API) separator sludges, dissolved air flotation (DAF) sludges, slop oil and tank bottoms, heat exchanger bundle cleanings, drilling muds and cuttings, and biological sludges.

Vendors claim that variations of this technology can treat virtually all organic wastes, including polychlorinated biphenyls (PCBs), pentachlorophenol (PCP), dioxins, creosotes, pesticides, wood preservatives, solvents, coal tar wastes, and chlorinated organics.

This technology is not designed to treat heavy-metal-contaminated wastes. However, some higher-temperature units can be used to treat mercury since mercury has a boiling point below 700°F.

Thermal distillation uses equipment that is commercially available and demonstrated. Variations of this technology are available from several vendors.

Technology Cost
As with most cleanup technologies, the factors that have an influence on the cost of treatment include the characteristics and quantity of the material to be treated, the contaminant concentrations, and the cleanup goals (D10185Z, p. 23).

The costs of treatment by thermal distillation depends largely on the treatment capacity of the unit used. For maximum cost-effectiveness, systems should be designed for the highest reasonable throughput (D15462L, p. 424). A graph on page 424 of D15462L shows the relationship between throughput and treatment costs. For a system operating 7000 hours per year at 2 or less tons per hour (tph), the costs range from $125 to $350 per ton and are more often on the high side of that scale. A system operating at a rate of 10 to 20 tph incurs costs between $50 and $75 per ton. The cost declines sharply between 0 and 2 tph, then continues to decline until it nearly bottoms out at about 15 tph (D15462L, p. 424).

One vendor with a 1- to 2-tph thermal distillation unit estimates that treatment will cost from $200 to $500 per ton of waste (D15461K, p. 7). A third source quotes its technology at $250 to $350 per ton, on an average job of treating 10,000 tons of waste (D126249, p. 2).

Therefore, depending on the processing rate and other site-specific factors, the cost of treatment using thermal distillation ranges from $40 to $500 per ton of material treated. Thermal distillation is significantly lower in cost than incineration and is price competitive with other treatment options (D15462L, p. 420).

Information Sources

D10185Z, VISITT 4.0, 1996

D126249, National Institute of Environmental Health Services, date unknown

D15462L, Steven R. Heuer, 1990

T0205

Diversified Remediation Controls, Inc.

Turbostripper

Abstract

The Turbostripper™ is an air stripper technology for removal of volatile organic compounds (VOCs) from groundwater or wastewater. According to the vendor, it is a 100% nonclogging unit, based on its use of the patented Turbofill chemically resistant plastic ellipsoids.

In early 1995 Diversified Remediation Controls (DRC) partnered with a United Kingdom corporation to introduce the patented Turbostripper into the U.S. market.

The design and engineering of the Turbostripper was focused on the elimination of clogging, which has been one of the major problems with air stripping technologies. The Turbostripper utilizes a patented fluidized-bed technology, called Turbofill™, in which hollow, chemically resistant ellipsoids create a violent, turbulent pattern within the fluidized bed. As a result, these ellipsoids break the laminar flow patterns common in packed-column air strippers, and significantly increase mass and heat transfer. This constant motion also keeps the inside of the unit free from buildup of materials that cause some other technologies to foul and clog, resulting in decreasing efficiencies, system shutdown, costly cleaning, and hazardous waste disposal issues. The Turbostripper can deal with high levels of silt or iron in the water to be treated and will not clog.

This technology is not designed for treatment of metals or certain other inorganics. All information was provided by the vendor and has not been independently verified.

Technology Cost

No information available.

T0206

Divesco, Inc.

Soil Washing

Abstract

According to the technology developer, the Divesco ex situ SRS-10 soil washing system combines physical separation with a special hydrocarbon mitigation agent that enhances the removal of light and heavy oils, gasoline, organic liquids, solids, and other contaminants. The developer claims that the system can treat heavy metals by adding an ozone generator.

The soil washing system treats soil and can potentially treat nonmunicipal sludge, solids (e.g., slag), and natural sediment. The Divesco system cannot treat asphalt and tars.

The Divesco SRS-10 soil washing unit is mobile and is mounted on a double-axle flatbed trailer to facilitate transport to contaminated sites.

Divesco, Inc., is no longer actively involved in remediatory work, and the technology is not commercially available.

All information is supplied by the vendor and has not been independently verified.

Technology Cost

The cost of the Divesco soil washing system ranges from \$50 to \$65 per ton of waste treated (D10161R, p. 8).

The following factors affect the cost of the technology (D10161R, p. 8):

- Site preparation
- Waste handling/preprocessing
- Residual waste characteristics
- Moisture content of soil
- Soil characteristics
- Depth of contamination
- Target contaminant concentration
- Depth to groundwater
- Initial contaminant concentration
- Waste quantity
- Amount of debris contained in waste

Information Source

D10161R, VISITT 4.0

T0207

Doe Run Company

TERRAMET

Abstract

The Doe Run Company provides treatment and recycling through its TERRAMET Service program. The services are based upon the core technologies of TERRAMET™ and pyrometallurgical metal recovery. TERRAMET is a commercially available extraction process used to leach heavy metals (especially lead) from contaminated soils, sludges, dust, and sediment. The process uses soil washing in conjunction with acidic leaching to remove metals. These metal-enriched solutions then undergo a metals recovery phase, which transforms the leached metals into their metallic states, after which the heavy metals concentrate is processed through pyrometallurgical circuits. The technology has been applied to lead, antimony, cadmium, chromium, copper, mercury, nickel, zinc, and silver. The TERRAMET equipment is mobile, allowing for on-site processing or fixed-site treatment at The Doe Run Company's Boss, Missouri, location (personal communication, M. Thomas, The Doe Run Company, 10/97).

The following advantages are claimed for TERRAMET processing:

- The leachant is tailored to the substrate and the contaminant, minimizing chemical additives.
- Leachant is fully recycled within the treatment plant.

- Treated soil can be returned on-site or used by Doe Run as part of the company's operations.
- All soil fractions can be treated.
- The end products are cleaned soil and recycled metal.
- No waste is generated during processing.

The TERRAMET process is specifically matched to the soil type, contaminant addressed, and metals concentration of the soil based on results of treatability tests. The presence of surfactants can hinder operations. High levels of carbonates or oxides can cause excessive leachate consumption or foaming. Processing soils with metal concentrations in excess of 100,000 parts per million (ppm) (10% by weight) may be best accomplished with direct pyrometallurgical processing, which is often more cost effective for soils with substantially higher heavy metals content.

Direct pyrometallurgical processing of heavy-metals-contaminated soils, sands, and dust is often better suited for materials with higher levels of contamination; however, it can be effective for low-level contamination as well. The technology is also well suited to process-concentrated heavy metals that have been generated by on-site screening or soil washing (personal communication, M. Thomas, The Doe Run Company, 10/97).

Technology Cost

In 1993, costs estimated for TERRAMET processing ranged from $100 to $200 per ton ($110 to $220 per metric ton). Major factors affecting cost include the quantity of waste, labor costs, soil characteristics, initial contaminant concentration, and target contaminant concentration. Factors having a lesser effect on project costs include site preparation, waste handling and preprocessing, the amount of debris associated with the waste, moisture content of the wastes, depth of the contamination, depth to groundwater, and the characteristics of the residual wastes (D10177Z).

For material processed at the company's Resource Conservation and Recovery Act (RCRA) permitted facility, economies of scale are achieved by integrating with the pyrometallurgical circuit. The result is a more cost-effective treatment in many cases (personal communication, M. Thomas, The Doe Run Company, 10/97).

TERRAMET technology was accepted into the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Emerging Technology Program in 1992. Based on results from that evaluation, TERRAMET technology was accepted into the SITE Demonstration Program in 1994. The demonstration took place in August 1994 at the Twin Cities Army Ammunition Plant in New Brighton, Minnesota. Cost estimates for soil treatment at the site were approximately $210 per ton ($230 per metric ton). This amount includes the cost of removing ordnance from the soil (D10697I, p. 47).

Information Sources

D10177Z, VISITT 4.0, 1995

D10697I, U.S. EPA, 1995

T0208

Donald J. Geisel & Associates, Inc.

HeatTrode Thermally Accelerated In Situ Bioremediation

Abstract

Donald J. Geisel & Associates, Inc., has developed a technology that uses devices called HeatTrodes to warm soil contaminated with organic compounds, accelerating in situ bioremediation. The HeatTrodes recirculate hot water or some other heat transfer fluid from an existing heat

source or a small, on-site boiler, forming a closed-loop heat distribution system. The system can also function as an air delivery system for bioventing. The technology is commercially available.

The vendor makes the following claims about HeatTrode technology:

- HeatTrodes can function as in situ heat exchangers to achieve effective warming rates for bioremediation and soil vapor extraction processes.
- HeatTrodes can be used for bioventing air delivery or to deliver microbes, nutrients, or fluids for the control of moisture and pH levels.
- HeatTrodes can be easily installed and operated, and a majority of the materials used in a typical installation can be reused in future installations.
- HeatTrodes can extend the effective cleanup season by providing warm soil conditions year-round in cold climatic regions.

While soil warming capabilities would not be affected by soil type, it is necessary to assess the porosity of the targeted soil or clay to determine if bioventing would be possible.

Technology Cost

In 1997, it was estimated that it would cost approximately $30 to $50 per ton to remediate soil contaminated with volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) using HeatTrode technology. The computer model estimate was based on inputs from testing performed by the University of Buffalo and the United States Air Force (D17162K, p. 12).

Inputs were provided to the cost model for an Alaskan site with an area of 10,000 ft^2 and a soil density of 100 lb/ft^3. The specific heat of the soil was 0.20 British thermal units (Btu) per pound per degree Fahrenheit. The HeatTrode centerline distance was 5 ft, and each HeatTrode was installed to a depth of 10 ft (D17162K, p. 12).

It was estimated that the system would operate for 183 days, and that 360 hr of heating would be required to achieve steady-state temperatures. This was estimated to be sufficient to raise the temperature of the soil from 25°F (ambient soil and air temperature) to 90°F (D17162K, p. 12).

Labor required to install the system was estimated to include machinists, welders, plumbers, and electricians, in addition to other site labor, supervision, and project management. The system required water, gas, and electricity (D17162K, p. 12).

System capital costs were estimated to be $85,557. Installation and tear-down costs were estimated to be $63,336. Energy costs were estimated to be $11,430. Total costs were estimated to be $183,740. The cost per cubic yard was estimated to be $41.34. The cost per ton was estimated to be $30.62 (D17162K, p. 12).

Information Source

D17162K, Donald J. Geisel & Associates, Inc., 1997

T0209

Dow Chemical Company

Dowex Ion Exchange Resins

Abstract

Dowex™ ion exchange resins include a range of anion and cation resins for multibed demineralization, mixed-bed condensate polishing, as well as nuclear and other specialty applications. Most Dowex resins are based on styrene copolymerized with divinylbenzene (DVB). According to Dow, styrene/DVB structures are the preferred matrices for ion exchange resins because

they offer significant capacity and stability advantages over acrylic, polyamine, and phenolic resin structures. Other applications for Dowex resins include air pollution control and solvent recovery.

This technology is currently commercially available.

Alternate exposures of resins to high and low concentrations of electrolytes can cause cracking and breakage due to alternate contraction and expansion. Eventually there may be significant reduction in particle size, causing increased resistance to flow and subsequent resin losses.

Ion exchange resin fouling can result from the use of a contaminated regenerant and result in channeling of flow with its attendant problems.

Exposure of ion exchange resins to highly oxidate environments can shorten resin life.

Technology Cost

No available information.

T0210

Dow Chemical Company

Dowex Optipore Adsorbent

Abstract

Dowex™ Optipore™ is a polymeric adsorbent used to treat chlorinated volatile organic compound (CVOC) contaminated off-gas streams from remediation processes such as air stripping of groundwater and soil vapor extraction. According to the vendor Dowex Optipore adsorbent has the following advantages over activated carbon:

- CVOC capacity much less affected by relative humidity
- Faster and more complete thermal desorption
- Better dynamic performance in a column—quicker restoration of sorption capacity
- Not friable—low attrition

This technology is currently commercially available.

All information is from the vendor and has not been independently verified.

Technology Cost

Cost is in the range of \$55 to \$65 (1994 dollars) per kilogram Dowex Optipore (D15538O).

Information Source

D15538O, Mackenzie et al., 1994

T0211

Enco-Tec Environmental Technology Systems, Ltd.

Enco-Tec RS30 Thermal Desorption

Abstract

Enco-Tec Environmental Technology Systems, Ltd. (Enco-Tec), offers the Enco-Tec RS30 thermal desorption system. The system is mobile and is used for the ex situ treatment of soils contaminated with petroleum hydrocarbons. The RS30 thermal desorption system is commercially

available and has been used at full-scale remediation projects in Canada. The vendor states that the technology is currently being aggressively marketed in the United States, Central and South America, and Great Britain.

Enco-Tec claims the following advantages for the RS30 thermal desorption system:

- Eliminates liability.
- Reduces treatment costs, since soils are treated on site.
- Allows treated soil to be used as backfill.

The RS30 thermal desorption system is not designed to treat polychlorinated biphenyls or heavy metals.

Technology Cost
In 1996, the vendor stated that soil treatment costs using the Enco-Tec low-temperature thermal desorption system began at approximately $40 per metric ton of soil treated. These costs include excavation and backfilling. Factors listed as influencing costs were the nature and concentration of site contaminants in the soil (D187717, p. 2).

Information Source

D187717, Enviro Access, 1996, web page

T0212

Dual-Phase Extraction — General

Abstract
Dual-phase extraction — also called two-phase vacuum extraction, dual-vacuum extraction, or vacuum-enhanced extraction — is an in situ, commercially available technology for the treatment of soils and groundwater contaminated with volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs).

Dual-phase extraction accelerates site remediation by simultaneously extracting contaminated liquid and soil vapor from the subsurface. The technology can be used to treat soil or groundwater contaminated with chlorinated solvents and petroleum hydrocarbons.

Dual-phase extraction is generally combined with bioremediation, air sparging, or bioventing when the target contaminants include long-chained hydrocarbons. Use of dual-phase extraction with these technologies can shorten the cleanup time at a site. For a specific example of dual-phase extraction, see summary T0117 for more information on bioslurping — vacuum-enhanced pumping combined with bioventing. The technology can also be used with pump-and-treat technologies to recover groundwater from high-yielding aquifers.

Dual-phase extraction cannot remediate heavy chlorinated compounds, pesticides, or heavy hydrocarbons including polychlorinated biphenyls (PCBs), dioxin, fuel oil No. 6, or metals (with the possible exception of mercury). High-velocity pump systems (such as liquid ring vacuum pumps) tend to form emulsions, especially when diesel fuel is part of the recovered fluids. The problem of emulsion can be solved with prepump separation or a de-emulsification unit.

Technology Cost
The U.S. Department of Defense (DOD) estimated the cost of dual-phase extraction to range from $85,000 to $500,000 per site in 1994 (D10925B, p. 4–146).

The costs of three sizes of a proprietary dual-phase extraction system were estimated in 1991. The costs associated with Radian International's AquaDetox/SVE system (see summary T0641) are detailed in Table 1. The system uses a moderate vacuum stripping tower and low-pressure

TABLE 1 Estimated Costs Associated with AquaDetox/SVE Systems

	Estimated Costs (1991 $)		
Item	500 gpm[a]	1,000 gpm[a]	3,000 gpm[a]
Site preparation[b]	650,000	930,000	1,350,000
Permitting and regulatory[b]	90,000	130,000	190,000
Capital equipment[b]	1,800,000	2,600,000	3,800,000
Startup and fixed costs[b]	110,000	121,000	161,000
Labor[c]	71,000	71,000	110,000
Supplies and consumables[c]	53,000	73,000	96,000
Utilities[c]	165,000	279,000	734,000
Effluent disposal (municipal system)[c]	160,000	320,000	960,000
Residuals and waste shipping, handling, and transportation[c]	0	0	0
Analytical[c]	21,000	21,000	21,000
Equipment repair/replacement[c]	41,000	58,000	76,000
Site demobilization[b]	500,000	500,000	500,000
Total one-time costs	3,150,000	4,281,000	6,001,000
Total annual O & M costs	511,000	822,000	1,997,000

Source: From D104552.
[a] gpm = gallons per minute.
[b] One-time costs.
[c] Annual operation and maintenance costs.

steam to treat contaminated groundwater and granular activated carbon (GAC) to treat soil vapor (D104552, pp. 1, 22).

Information Sources

D10925B, U.S. DOD, October 1994
D104552, U.S. EPA, October 1991

T0213

Duke Engineering & Services, Inc.

Chemically Enhanced Solubilization for Aquifer Remediation (CESAR)

Abstract
The CESAR (chemically enhanced solubilization for aquifer remediation) technology is a surfactant-enhanced pump-and-treat technology that remediates an aquifer by treating organic contaminants with a chemical surfactant solution. The surfactant solubilizes the contaminants, thus making them more readily transportable to the extraction wells. This technology is currently commercially available.

CESAR was developed to address the problem of locating, characterizing, and removing dense non-aqueous-phase liquids (DNAPLs) from contaminated aquifer systems. The process is particularly suited to remediating groundwater contaminated with chlorinated solvents, such as trichloroethylene (TCE), tetrachloroethene (PCE), trichloroethane (TCE), and carbon tetrachloride (CCl_4). According to the vendor, CESAR can also be applied to sites contaminated with creosote, polychlorinated biphenyls (PCBs), Freon 113, volatile organic compounds (VOCs),

pesticides, herbicides, semivolatile organic compounds (SVOC's), polycyclic aromatic hydrocarbons (PAH), dense and light non-aqueous-phase liquids (DNAPL & LANPL), explosives, total petroleum hydrocarbons (TPH), and benzene, toluene, ethylbenzene, and xylenes (BTEX).

The CESAR process is only applicable to organic contaminants. It is also limited to use in relatively permeable granular geological materials, such as sands and gravels in which there is sufficient permeability to transport the surfactant solution to the NAPLs; however, it is unlikely that the NAPLs would enter unfractured geological materials much finer than silty sands. The process is not applicable for use in fractured rock because of the potential for unwanted mobilization of NAPL pools through fractures when the pool is contacted by surfactant solution. To some extent this can be prevented by choosing the proper surfactant and hydraulically pressurizing the deeper sections of the rock.

Technology Cost

Costs for CESAR vary greatly, depending on site characteristics, the amount of dense non-aqueous-phase liquid to be solubilized, the depth of the aquifer, the amount and concentrations of clay and many other considerations (D13756O, p. 238).

According to the vendor, remediation activities cost $1200/gal to remove dense non-aqueous-phase liquids from groundwater at the Hill Air Force Base in Utah (D14795Z, p. 1).

Information Sources

D13756O, Ground Water Monitor, December 2, 1993

D14795Z, Intera, Inc., 1996

T0214

E.I. DuPont De Nemours & Company/Oberlin Filter Company

Microfiltration Technology

Abstract

The DuPont/Oberlin microfiltration technology is a submicron filtration process that can be used to treat landfill leachate, groundwater, and liquid industrial wastes containing soluble and insoluble metals, particulates, and other suspended solids. Superfund and Resource Conservation Recovery Act (RCRA) corrective action sites are among the potential sites for applying this technology to groundwater contaminated with metals from electroplating/metal finishing wastes and semiconductor and other electronic component manufacturing waste streams. Other potential applications for this technology include metal forming and uranium manufacturing wastes, in addition to other sources of metal-bearing wastes.

This technology removes dissolved metals from liquid wastes at a lower cost then other treatment options, such as precipitation followed by clarification and conventional filtration, ion exchange, reverse osmosis, and electrolysis. An advantage of the DuPont/Oberlin microfiltration technology is that it produces a dry, stabilized cake that can be landfilled when used in conjunction with a filter aid/cake stabilizing agent.

Technology Cost

No general cost information is given for the DuPont/Oberlin microfiltration technology. However, specific cost information is provided in the case study for the Palmerton Zinc Superfund (PZS) site. A document entitled "DuPont/Oberlin Microfiltration Technology (SITE)" contains a table (Table I) on page 10 that shows the filtration media cost per gallon of waste filtered (D12108U, p. 10).

Information Source

D12108U, Mayer, November 1992

T0215

DuraTherm, Inc.

DuraTherm Desorption

Abstract
DuraTherm, Inc., offers the DuraTherm Desorption™ technology to treat soil and sludges contaminated with volatile organic compounds (VOCs). The technology pulverizes the contaminated media and uses high-temperature thermal desorption techniques to remove targeted contaminants in a nonoxidizing atmosphere that minimizes creation of toxic by-products. VOCs are separated and recovered. All wastes are treated at a centralized facility in Houston, Texas.

The vendor states that DuraTherm Desorption technology is protected by one or more of the following patents: 4,872,954; 5,078,836; 5,227,026; 5,523,060; and 5,851,361. According to the vendor, DuraTherm Desorption is currently commercially available and has been used in the cleanup of 75 sites.

Thermal desorption technology is not suitable for inorganic wastes unless additional treatment methods (such as stabilization) are applied after DuraTherm processing. Excavated wastes or wastes containing large debris should be preprocessed with shredding or screening equipment. Herbicides or pesticides with extremely low volatility will be difficult to treat to regulatory levels.

Technology Cost
The estimated costs for DuraTherm Desorption technology range from $100 to $350 per ton of waste material treated. It was not specified if all indirect costs associated with treatment such as excavation, permits, and treatment of residuals, were included in the above estimate (D152012, pp. 33, 34).

Factors that have a significant effect on DuraTherm Desorption technology costs include the following:

- Amount of debris
- Initial contaminant concentration
- Characteristics of residual wastes
- Waste handling/preprocessing
- Quantity of waste
- Moisture content of soil
- Target contaminant concentration
- Characteristics of soil (D152012, pp. 33, 34)

In 2001, the U.S. Environmental Protection Agency (EPA) published a cost analysis of various remediation technologies, including thermal desorption. Thermal desorption technology costs were analyzed based on operation and maintenance (O & M) costs, capital costs, and other site-specific data (D22449H, p. 3-1).

In the cost analysis, thermal desorption was demonstrated to have a measurable economy of scale. Unit costs for the treatment of less than 20,000 tons of soil ranged from $100 to $300 per ton. Unit costs decreased to less than $50 per ton for applications treating relatively larger quantities of soil. It was stated that clay content, particle size, moisture content, and pH of the soil will impact pretreatment costs. Also, applications treating high concentrations of chlorinated hydrocarbons will generally require higher temperatures and more extensive off-gas treatment (D22449H, pp. 3-1, 3–4).

Information Sources

D152012, VISITT Version 5.0, 1996
D22449H, U.S. EPA, 2001

T0216

DustMASTER Enviro Systems

DustMASTER

Abstract
The DustMASTER system is designed to limit dust from fly ash and other dust generating waste streams such as fly and bottom ash from waste-to-energy and utility plants, cement kiln dust, baghouse residue, iron-oxide, and other powder-type materials.

According to DustMASTER Enviro Systems, they have tested the DustMASTER for 10 years on a wide variety of different wastes. Over the last few years the emphasis has been on fluidized-bed combustor fly ash. The product has been commercially available for several years and many units are in full-scale operation.

Technology Cost
No available information.

T0217

Dutch Pride Products

EcoPlus

Abstract
Dutch Pride Product's EcoPlus technology was developed as a dispersant for spilled oil floating on water, in soil, or on machinery. EcoPlus is designed to facilitate breakup of the oil film into small droplets through agitation and brushing. According to the vendor, this reduces both toxic and environmental effects of the oil and the increased surface area makes the oil more accessible to microorganism degradation.

EcoPlus is not designed to handle large amounts of oil that can be removed by physical means.

Technology Cost
No available information.

T0218

Dynaphore, Inc.

Forager Sponge Technology

Abstract
The Forager™ sponge technology is a volume-reduction technology in which heavy metal and inorganic contaminants from aqueous media are selectively concentrated into smaller volumes. The Forager sponge is an open-celled cellulose sponge containing a chelating polymer with selective affinity for dissolved heavy metals in both cationic and anionic states from groundwater, surface water, landfill leachate, and industrial effluents. This technology has been commercially available for about 4 years and can be used in situ or groundwater can be extracted and treated ex situ.

Amine groups in the polymer provide selective affinity for heavy metals in both cationic and anionic states and preferentially form coordination complexes with transition-group heavy

metals such as cadmium, copper, iron, gold, and manganese. The sponge has high selectivity for heavy metals and low selectivity for alkali and alkaline earth metals (such as sodium, potassium, magnesium, and calcium ions). This property is useful in treating contaminated natural waters that may contain high concentrations of alkali or alkaline earth metals. In pollution control applications, the sponge has been found useful in scavenging toxic metals in parts per million (ppm) and parts per billion (ppb) concentrations.

Advantages of the Forager sponge include the following:

- Suitability for unattended use in some situations.
- Sponges can be cleaned and reused several times.
- Concentrates waste into a smaller volume thereby facilitating disposal.
- Performance is relatively unaffected by suspended solids.
- Vendor claims competitive cost.

Limitations of the technology include the following:

- Limited to heavy metals and inorganics in aqueous media.
- Not useful in situations where high levels of oily substances or high concentrations of phosphate and silicate ions are present.
- Affinity and absorption capacity depends on pH, heavy-metal concentration, type, amount, and concentration of other ions present, and the presence of complexing agents.
- Sponges cannot sustain compressive forces.
- Reaction rate can be limited by temperature.

Technology Cost

The EPA Innovative Technology Evaluation Report gives a detailed cost estimate for operating the Forager sponge technology in remediating the heavy-metal contaminants cadmium, lead, and copper from 525,000 gal ($1.99 \times 10^3 m^3$), of groundwater over a 1-year period in 1994. The economic analysis is based on assumptions and costs provided by Dynaphore, Inc., and on the results from the 4-day Superfund Innovative Technology Evaluation (SITE) demonstration. The economic analysis assumes that the contaminants are treated using a four-column, pump-and-treat unit to the percent removal claimed by the vendor. The cost estimate includes site preparation, capital equipment, startup, consumables and supplies, labor, utility costs, and shipping and handling of residuals and wastes. The cost does not include site-specific engineering aspects beyond the scope of the SITE project, nor does it include costs for functions assumed to be the obligation of the responsible parties and/or site owners. The cost figures are order of magnitude estimates, generally +50 to −30% (D10428Z, p. 47).

The first costing scenario assumes that the sponges are used once and are replaced when saturated by cadmium ion (this ion saturates the sponge more quickly than does lead or copper). The second costing scenario assumes that the sponges can be regenerated twice by acid treatment, thus providing three treatment cycles. The groundwater treatment cost with replacement was estimated at \$340 per 1000 gal (\$90/m^3) treated compared to \$238 per 1000 gal (\$63/m^3) for regeneration. However, it is important to note that regeneration may not always be feasible.

The effective absorption capacity of the sponge has the most significant impact on the cost because it determines the frequency of replacement or regeneration. Thus, for copper, the estimated cost for groundwater treatment is \$124 per 1000 gal (\$33/m^3) for replacement and \$104 per 1000 gal (\$28/m^3) for regeneration. An evaluation that considers the volume to be treated, the identity and concentration of contaminants, the concentrations of co-occurring ions, and design and operating parameter choices is required to arrive at the most cost-effective plan of action.

In another application, for a private client, the sponge was used to remove arsenic ions from contaminated wastewater at a bulk fueling terminal. The sponge was used as the finishing technology for water that had been pumped through an air stripper and a granulated carbon bed. In this case, 378,000 gal ($1.43 \times 10^3 m^3$) of water was treated at an approximate cost of \$0.013/gal (\$0.0034/liter)(N. Hart, personal communication).

The vendor claims the overall cost of metal removal is typically about \$0.60 per gram of metal absorbed, based upon a one-time use of the sponge. By regenerating and recycling the sponge, it is possible to achieve lower operational costs (N. Ranier, personal communication).

Information Sources

D10428Z, Vaccaro and Kitaplioglu, EPA SITE Demonstration Report, June 1995

Nick Hart, personal communication, September 11, 1996

Norman B. Ranier, personal communication, February 27, 1997

T0219

E Products, Inc.

Venturi Thermal Oxidizer

Abstract

E Products, Inc. (EPI) is an environmental manufacturing firm that designs treatment systems for contaminated soil, air, and groundwater. The EPI Venturi Thermal Oxidizer™ is designed to destroy petroleum hydrocarbon fumes by combustion. By using common extraction technologies, the unit can be used to remediate contaminated soil or groundwater. The heat generated can be recovered to aid in preheating the inlet stream or simply vented to the atmosphere. According to information from the vendor received in September of 1999 and March of 2000, the company is closed for business and the EPI Venturi Oxidizer has been sold to a company called Mytec from Green Bay, Wisconsin.

The vendor states that the Venturi Thermal Oxidizer has been used in the field and is approximately 30% more efficient and can handle a wider range of contaminants than typical thermal oxidizers.

EPI lists the following advantages of catalytic thermal oxidation technology:

- Allows for a final solution to waste disposal.
- Allows for economical heat recovery.
- Accommodates high hydrocarbon concentrations, for those fume streams fuel requirements are reduced to practically zero.
- Allows fumes containing 16% or more oxygen gas to be used as the source of combustion air.
- Requires minimum maintenance because there is no problem with fouling or future disposal problems.

The Venturi Thermal Oxidizer does not destroy inorganic contaminants. Fumes with a dew point over 120°F should be cooled, condensed, and moisture separated to minimize fuel costs. The system may not be cost effective for contaminant waste streams with low lower explosive limit fume streams. Information in this summary is from the vendor and has not been independently verified.

TABLE 1 Remediation Venturi Thermal Oxidizer Rental Price List

Model	Monthly Rental Price	Weight in Pounds	Comments
Venturi-100H	$3,220.00	1,000	Horizontal skid base
Venturi-200H	$3,850.00	2,600	Horizontal skid base
Venturi-200C	$4,130.00	2,800	Catalytic skid base
Venturi-200T	$4,170.00	3,800	Horizontal trailer mounted
Venturi-500H	$3,970.00	3,100	Horizontal skid base
Venturi-500C	$4,090.00	3,450	Catalytic skid base
Venturi-500T	$4,340.00	4,000	Horizontal trailer mounted
Venturi-1000H	$4,380.00	4,500	Horizontal skid base
Venturi-1000C	$4,920.00	5,100	Catalytic skid base
Venturi-1000T	$4,770.00	6,300	Horizontal trailer mounted
Venturi-1500H	$5,390.00	5,600	Horizontal skid base
Venturi-1500C	$6,850.00	6,400	Catalytic skid base
Venturi-1500T	$5,810.00	8,000	Horizontal trailer mounted

Source: Adapted from D17730U.

TABLE 2 Operational Parameters for Soil Remediation Thermal Oxidizers

	Venturi Model Number			
Category	200H	500H	1000H	1500H
Maximum Btu loading	300,000	750,000	1,500,000	2,250,000
Maximum flow capacity in scfm[a]	200	500	1000	1500
Maximum VOC destruction in lb/hr	15	36	73	109
Dimensions in feet	$10 \times 4 \times 8$	$11 \times 4 \times 8$	$13 \times 5 \times 8$	$16 \times 5 \times 8$
Weight in pounds	2,600	3,100	4,500	5,600
Horsepower for blower	0.5	0.5	0.5	0.5
Operating temperature, °F	1,400	1,400	1,400	1,400
Retention time in seconds	0.5	0.5	0.5	0.5
Energy use in MMBtu/hr[b]	0.31	0.79	1.57	2.36
Propane in scfh[c]	125.6	314.0	628.0	942.0
Propane cost in $/day	69.91	174.78	349.56	524.34
Natural gas usage in scfh	314	785	1570	2355
Natural gas costs in $/day	36.46	91.15	182.30	273.45
Power supply	230 VAC[d] or 460 VAC, 60 Hz, 1 phase			

Source: Adapted from D17730U.
[a] scfm = standard cubic feet per minute.
[b] MMBtu/hr = million British thermal units per hour.
[c] scfh = standard cubic feet per hour.
[d] VAC = volts of AC current.

Technology Cost

To determine if thermal oxidation is cost effective at a given site, the following criteria are evaluated: contaminant flow rate, inlet contaminant concentration, regulatory requirements, fuel costs, and uses for heat recovery of the combustion waste stream (D17730U, p. 3).

Information on rental costs for EPI's Venturi Thermal Oxidizer is given in Table 1. Information on utility costs of various venturi models is given in Table 2.

Information Source

D17730U, E Products, Inc., undated vendor literature

T0220

E.W.M.C. International Inc.

Emery Microwave Process

Abstract

The Emery microwave process is a patented, ex situ technology for the treatment of soil and water contaminated with polychlorinated biphenyls (PCBs) and other hazardous compounds. The vendor states that the technology uses microwave energy to break the bonds of long-chain hydrocarbons.

According to E.W.M.C. International Inc., the Emery microwave process has been used commercially to recycle rubber tires and process medical waste. Research and development is currently being conducted on the application of the technology to treat contaminated media. All information is from the vendor and has not been independently verified.

Technology Cost

According to the vendor, an Emery microwave process unit costs a minimum of $14 million dollars (D21475F, p. 3).

Information Source

D21475F, Manning, 1997

T0221

Eagle Environmental Technologies, Ltd.

Plasma Technique

Abstract

Eagle Environmental Technologies, Ltd. (EET) is currently developing the plasma technique system for the treatment of liquid or gaseous hazardous wastes. The system uses an electrically induced continuous-stream plasma reactor. Temperatures in the reactor can reach 5500°C. According to the vendor, treated materials are converted into virtually 100% benign or simple molecules that may form the basis of other usable products. The technology was developed in Hungary and has not yet been used in the United States. EET has the licensing rights to market the plasma technique worldwide, and the technology is commercially available.

EET claims the following advantages of the plasma technique:

- Destroys any and all hazardous liquid and gaseous wastes.
- Provides 100% elimination of wastes.
- Processes wastes using a closed-loop system.
- Allows for adjustments to be made relative to the customer's immediate needs, as technology is modular and mobile.
- Allows for continuous processing since failure of one unit will not shut down the entire processing system.

- Minimizes maintenance time required for repairs.
- Minimizes labor costs, energy costs, and liability costs.

Technology Cost
No available information.

T0222

Earth Purification Engineering, Inc.

Soil Cleanup System (SCS)

Abstract
The soil cleanup system (SCS) is a rotary kiln modified asphalt recycling unit for treatment of gasoline- and diesel-fuel-contaminated soils. This technology has been used in at least two full-scale demonstrations; however, its commercial availability is unknown because RIMS was unable to contact the vendor. The asphalt recycling unit was originally developed by Robert L. Mendenhall, a Las Vegas, Nevada, contractor who had successfully recycled asphalt for a number of years.

The system is mounted on two mobile trailers. The first trailer contains a rotary kiln in which soil is heated to 300 to 600°F. The off-gas is ducted from the rotary kiln to a cyclone separator where relatively coarse matter is removed and a heat exchanger cools the gas to about 400°F. The cooled off-gas goes to the baghouse, which filters relatively fine particles from the off-gas stream. The final unit is an afterburner or fume incinerator that heats the contaminated air to approximately 1800°F to destroy the contaminants.

Several problems arose during full-scale demonstrations of the technology, including difficulties in monitoring particulate emissions and in monitoring the process. Wide fluctuations were observed in key process parameters, including carbon monoxide, carbon dioxide, and oxygen levels, as well as afterburner temperatures.

Technology Cost
A demonstration was conducted with the California Department of Health Services in October 1988 at the U.S. Navy's 32nd Street Naval Station in San Diego, California. According to the technology developer, the cost to operate the demonstration project was \$174.00/yd^3 based upon 700 yd^3 of contaminated soil processed (D15638R, p. 8).

Information Source

D15638R, Remedial Technology Demonstration Project, California Department of Health Services, 1991

T0223

Earth Tech

Bioremediation — Solid-Phase

Abstract
The Earth Tech technology is an ex situ, soil bioremediation process that uses the indigenous microorganisms already present in the soil in a custom-designed approach to enhance microbial activity. The Earth Tech technology is used primarily to treat soil contaminated with petroleum hydrocarbons from fuels (such as gasoline, diesel, kerosene, etc.). In the Earth Tech process,

optimum degradation of petroleum hydrocarbons is achieved by soil pretreatment and by the addition of appropriate nutrient mixture.

According to the vendor, the Earth Tech technology can treat petroleum hydrocarbons, halogenated volatiles, halogenated semivolatiles, nonhalogenated volatiles, nonhalogenated semivolatiles, polynuclear aromatics (PNAs), solvents, benzene–toluene–ethylbenzene–xylene (BTEX), and organic acids. The technology can be used in the following industrial applications or waste sources: dry cleaners, gasoline/service station, petroleum refining and reuse, pulp and paper industry, and wood preserving.

Among the advantages of the Earth Tech treatment system are its mobility and its suitability for on-site treatment of petroleum hydrocarbon contaminants. The technology was formerly commercially available, but Earth Tech no longer offers it for remediation purposes.

Among the limitations of the Earth Tech technology are:

- Earth Tech's bioremediation facility can only accept and treat soils contaminated by virgin petroleum hydrocarbons generated from leaking underground storage tank sites and is not permitted for used petroleum products containing metals, such as waste oils.
- Earth Tech's full-scale system discharges any objects that are larger than 0.25 inches in diameter.
- Factors that affect biodegradation rates affect the cleanup efficiency of the technology.

Technology Cost

The vendor estimated price range for using the Earth Tech technology per unit of waste treated is \$20 to \$50/yd^3 (D10156U, p. 28).

The cost for using the Earth Tech technology at the following sites were as follows (D10156U, pp. 9–10, 13–15, 18–20, 23–25):

- Fort Bragg, NC (gasoline service station)—\$22/ton
- Fort Jackson, SC (gasoline service station)—\$26/ton
- City of Burlington, NC (gasoline service station)—\$22/ton
- Department of Transportation (gasoline service station)—\$22/ton

Among the factors that affect unit price are (D10156U, p. 28):

- Quantity of waste
- Labor costs
- Site preparation costs
- Target contaminant concentration
- Waste handling/preprocessing
- Characteristics of residual waste
- Initial contaminant concentration
- Amount of debris with waste
- Characteristics of soil
- Utility/fuel rates
- Moisture content of soil
- Depth of contamination

According to the vendor, the technology is very competitive with alternative treatment technologies and disposal alternatives when used to bioremediate petroleum-contaminated soils. When compared with thermal treatment, Earth Tech's bioremediation price is typically 10 to 30%

lower. When compared with landfills designed for petroleum-contaminated soils, the treatment price for bioremediation is typically 20 to 50% lower than the disposal costs (D10156U, p. 2).

Information Source

D10156U, VISITT 4.0

T0224

ECO Purification Systems USA, Inc.

ECOCHOICE

Abstract

ECO Purification Systems USA, Inc. (EPS) has patented the ECOCHOICE® process. This technology uses catalytic oxidation to destroy dissolved organic contaminants in a fixed-bed reactor. Ozone and the polluted water pass through the reactor where the organic contaminants are oxidized to form carbon dioxide and water. Clean water is discharged, and residual ozone is recycled or destroyed within the treatment system.

The ECOCHOICE process can be used for treating drinking water, groundwater, industrial wastewater, landfill leachates, and bio-filter effluent. ECOCHOICE has been used at a groundwater treating operation at a military site in Tennessee to treat nitroaromatics.

EPS is also conducting trials on textile dye wastewater using a mobile pilot plant that will also be used to treat solvent-contaminated wastewater at an automotive facility.

The vendor claims that this process consumes significantly less ozone than conventional systems currently in use and operates at a lower variable cost. The vendor also claims that the process operates at ambient temperatures and atmospheric pressure that could allow for reduced capital cost expenditures and the potential for improved reliability compared to conventional ozone processes.

Technology Cost

The company has extrapolated data from pilot testing to make a rough price comparison between its technology and another company's ultraviolet (UV)/ozone/hydrogen peroxide system. The competing system was used for one year to treat 24 million gallons of groundwater contaminated with low levels of explosives at an U.S. Army site. The cost of the remediation was $96,813. EPS estimates that the ECOCHOICE system could have treated the same amount of groundwater for $15,450 because it requires less ozone, contains no UV lamps or chemicals, operates at ambient temperature and pressure, and generates no residual waste (D133459, p. 30). Refer to Table 1 for the comparison of ECOCHOICE costs to other advanced oxidation process (AOP) costs.

The treatment cost for the same amount of pinkwater (explosive manufacturing wastewater) was $23,700 for conventional carbon regeneration as compared to $22,100 for the use of ECOCHOICE (D13609E, p. 3).

Cost data has also been generated from the pilot-scale testing of the treatment of trinitrotoluene- (TNT-) and dinitrotoluene-contaminated water. Treatment costs range from $0.60 per 1000 gal for mildly contaminated water [<70 parts per billion (ppb) TNT], to $3.88 per 1000 gal for more contaminated water (2000 ppb TNT) (D14344C, p. 204).

Based on the U.S. Department of Defense's (DOD's) pilot-scale demonstration at the Volunteer Army Ammunition Plant in Chattanooga, Tennessee, ECOCHOICE is capable of reducing the concentrations target contaminants to less than 3 ppb. At a flow rate of 24 million gallons of contaminated groundwater per year, treatment costs would average $3.00 per 1000 gal (D20947M, p. 2).

TABLE 1 Cost Comparison of ECOCHOICE to Other Advanced Oxidation Processes (AOPs)

Groundwater Flow: 732 gal/min
COD Removal: ranges from 50 to 30 mg/liter
TOX Removal: ranges from 400 to <10 μg/liter

	Vendor 1 ($/year)	Vendor 2 ($/year)	Vendor 3 ($/year)	ECOCHOICE ($/year)
Capital costs	1,325,000	1,575,000	1,695,000	1,690,000
Annual costs				
UV energy	772,600	735,000	44,300	0
Lamp replacement	0	0	22,600	0
Hydrogen peroxide	192,300	448,000	65,700	0
Acid	17,000	33,000	0	0
Base	74,000	147,000	0	0
Catalyst	0	19,000	2,000	0
Ozone electricity	0	0	219,000	76,593
Liquid oxygen	0	0	0	168,894
Annual operating cost	1,145,900	1571,000	3536,000	300,358
Unit operating cost ($/1000 gal)	3.26	4.47	1.01	0.86

Source: From D13609E.

Information Sources

D133459, Industrial Wastewater, 1996

D13609E, ECOCHOICE

D14344C, Ground Water Monitor, 1996

D20947M, Johns, 2000

T0225

Ecology Technologies International, Inc.

FyreZyme

Abstract
FyreZyme™ is an aqueous biostimulation agent that enhances the degradation of a variety of organic contaminants. FyreZyme is a combination of bacterial growth enhancing agents, extracellular enzymes, and surfactants. The bacterial growth enhancers increase natural biological processes by stimulating a logarithmic growth phase of indigenous microbes in soil and water, while extracellular enzymes initiate the oxidation that degrades petroleum-based contaminants, and surfactants help desorb the petroleum bound to soil particles. FyreZyme nutrients sustain microbial populations as they continue to metabolize contaminants. In addition, FyreZyme contains a biodegradable compound that adds oxygen to the soil, thereby facilitating hydrocarbon degradation. After the petroleum is removed, oil-degrading microbial populations decrease to their original numbers.

FyreZyme, a proprietary product of Ecological Technologies International, Inc., is commercially available and has been utilized in full-scale field demonstrations on petroleum-contaminated soils and in groundwater.

The vendor claims the following advantages of the FyreZyme technology:

- Cost effective and easy to use.
- Decrease in remediation time.
- Environmentally safe.
- Can be used alone or in coordination with other technologies.
- Results in benign products such as water, carbon dioxide, and fatty acids.
- Contains a mix of different enzymes that act on nonspecific pathways.

The major limitations of this technology are those factors that limit bacterial growth, such as temperature extremes, pH (below 3 or above 10), and presence of other contaminants detrimental to bacteria life. Remediation of petroleum contaminants using FyreZyme can be accomplished under both aerobic and anaerobic conditions; however, remediation under aerobic conditions is faster and more complete. Other factors that may affect speed and completion of contaminant breakdown include moisture level, soil properties, and microbe mobility. In addition, the shelf life of FyreZyme is reduced from 5 to 2 years at temperatures above 100°F.

Technology Cost

The vendor claims FyreZyme's affordability is a key feature of this technology. One gallon (3.79 liters) of the FyreZyme concentrate will clean about 8 yd^3 (6 m^3) of contaminated media and will cost about \$55 (\$15 per liter). This estimate does not include engineering and other associated costs such as excavation, permits, and treatment of residuals (personal communication: Peter Condy, Ecology Technologies International, Inc., September, 1996).

Taking other associated costs into consideration, FyreZyme bioremediation for soil up to 14 inches (36 cm) in depth would cost \$17 to \$24/yd^3 (\$22 to \$31/m^3). For deeper contamination, the cost of FyreZyme treatment also increases. Depending on the depth of the contamination, total cost could reach \$55/yd^3 (\$72/m^3) (personal communication: Peter Condy, Ecology Technologies International, Inc., September, 1996).

According to the vendor, FyreZyme bioremediation technology is about 10% the cost of granulated activated carbon (GAC) when used as an in situ treatment of volatile organic compounds [VOCs] (D10149V, p. 2).

Information Sources

Ecology Technologies International, Inc., P. Condy, September 1996

D10149V, VISITT 4.0, 1995

T0226

Ecolotree, Inc.

Ecolotree Buffer

Abstract

The Ecolotree buffer uses phytoremediation, or plant processes, for environmental remediation purposes. Ecolotree buffers can be used to reduce the migration of subsurface water and surface runoff, while also acting as an in situ remediation technique for both organic and heavy-metal contaminants, including benzene, toluene, ethylbenzene, and xylene (BTEX); chlorinated solvents; ammunition wastes; and excess nutrients in soil or water. The technology is commercially available and has been used at landfill and waste treatment sites.

Buffers can be irrigated by industrial and municipal effluent to remove inorganic and organic compounds. In this application, the buffer is operated as a flow-through system that absorbs, sequesters, and metabolizes priority pollutants from the wastewater sources. It is often installed as the final filter at stream edges or around site perimeters. The buffer provides additional benefits as a visual barrier and it reduces noise, intercepts dust, and creates a wind break for operators. In addition, it can provide an aesthetic landscape for the neighborhood.

Buffers can also remediate soil contaminated with priority chemicals deposited by accidental spillage. Decomposing roots and leaves can increase soil organic carbon, thereby increasing soil adsorption. Plant oxygenated root zones enhance microorganism activity, which can increase the degradation rates of organic pollutants. Plants take up soluble organics and minerals and metabolize them or store them in tissues. Plants can also pump water from the soil, increasing the soil's oxidizing capacity.

Further investigation is needed to determine the fate of contaminants accumulated during phytoremediation. Evidence has shown that poplar trees degrade chlorinated solvents, such as trichloroethylene (TCE), through naturally occurring metabolic processes. The by-products, possibly carbon dioxide and chloride salts, may be stored in the tissues of the trees. It is not yet certain, however, the fate of many chemicals and metals. Contaminants that collect in the leaves may be released when the leaves drop, or may be eaten by animals and consequently bioaccumulated through the food chain.

In addition, soil toxicity could create problems with establishing plants at some sites, and in cold weather, the uptake of contaminants by trees is greatly reduced. Phytoremediation may be slower than excavation or ex situ treatment.

Ecolotree, Inc., offers a related technology called the Ecolotree cap. A discussion of the Ecolotree cap is included in the RIMS2000 library/database (T0227).

Technology Cost

In 1997, the U.S. Environmental Protection Agency published an overview of current information on phytoremediation of TCE. The report included cost information for an Ecolotree TCE phytoremediation system (D177815, p. 7). This information is summarized in Table 1.

Cost savings using poplar trees can range from $50,000 to $100,000 per acre ($120,000 to $140,000 per hectare) when compared to traditional waste control methods used at municipal

TABLE 1 Cost Estimate for the Use of Ecolotree Phytoremediation Technology to Remediate a Site Contaminated with Trichloroethylene (TCE)[a]

Activity	Cost
Tree installation (1450 trees per acre)	$12,000–$15,000
Predesign	$15,000
Design	$25,000
Site visit	$5,000
Soil cover and amendments	$5,000
Transportation to site	$2.14 per mile
Operation and maintenance	
Irrigated design	$1,500
Nonirrigated design	$1,000
Pruning (not every year)	$500
Harvest (during harvest years)	$2,500

Source: Adapted from D177815.

[a] Estimates will vary with the type of contaminant, treatment goal (containment vs. removal), and location.

landfills (D120661 p. 2). Monitoring costs are expected to be similar to those for other technologies (D133517).

The Oregon Department of Environmental Quality (ODEQ) in conjunction with CH2M Hill of Portland, Oregon, designed a phytoremediation database that lists cost information for phytoremediation projects in Oregon. Estimated costs for the 14.3-acre Ecolotree buffer used at Riverbend Landfill in McMinville, Oregon, were $45,000 for tree planting, $35,000 to $80,000 for monitoring, and $28,000 for irrigation. At this landfill, leachate is applied directly to the poplars for remediation (D19710Y, p. 7).

Because phytoremediation utilizes solar energy, the technology requires few energy inputs. This factor reduces operating costs. In addition, expenses are spread out over a greater time period than other technologies since phytoremediation is a slower treatment process. The result is lower annual costs. Frick et al. also note that "agronomic costs, including planting, tillage, fertilization, and harvesting, can be insignificant in comparison with associated administrative costs, such as site management, regulatory reporting, and analysis of data" (D20756H, pp. 42, 43).

Information Sources

D120661, Great Plains/Rocky Mountain Hazardous Substance Research Center web site, October 1995

D133517, Schnoor et al., 1995

D177815, U.S. EPA, 1997

D19710Y, Oregon DEQ, 1999

D20756H, Frick et al., 1999

D20764H, People, undated

T0227

Ecolotree, Inc.

Ecolotree Cap

Abstract

The Ecolotree cap is a commercially available phytoremediation technology that uses plants to create a protective cover for landfills to prevent water from penetrating industrial or municipal waste and forming leachate. The Ecolotree cap uses plants, particularly poplar trees such as the Carolina hybrid poplar, to create a low-maintenance, living cap. The cap acts as a "sponge and pump" to reduce water movement through buried wastes and prevent chemical leaks. In addition to protecting against leaching, the oxygenated root zone created by the plants enhances the microbial population in the soil, which fosters degradation of contaminants. Phytoremediation is best suited for sites contaminated with moderately hydrophobic compounds such as benzene, toluene, ethylbenzene, and xylenes (BTEX); chlorinated solvents; nitrotoluene ammunition wastes; and excess nutrients.

As an alternative to conventional landfill caps, Ecolotree caps offer low-maintenance systems with long-term durability. They are often significantly less expensive than conventional landfill caps. In addition, public acceptance of the technology can be very high, in part because of the parklike aesthetic that provides bird and wildlife habitat.

Further investigation is needed to determine the fate of contaminants accumulated during phytoremediation. Evidence has shown that poplar trees degrade chlorinated solvents, such as trichloroethylene (TCE), through naturally occurring metabolic processes. The by-products, possibly carbon dioxide and chloride salts, may be stored in the tissues of the trees. The fate of many chemicals and metals, however, is not yet certain. Contaminants that collect in the leaves may be released when the leaves drop, or may be eaten by animals and consequently

bioaccumulated through the food chain. In addition, soil toxicity could create problems with establishing plants at some sites. In cold weather, the uptake of trees is also greatly reduced.

Ecolotree, Inc., offers a related technology called the Ecolotree buffer. A discussion of the Ecolotree buffer is included in the RIMS2000 library/database (T0226).

Technology Cost

Planting costs for phytoremediation are approximately $10,000 per acre. Monitoring costs are expected to be similar to those for other technologies (D133517). At sites where poplar trees were used rather than traditional landfill caps, the savings have ranged from $50,000 to $100,000 per acre, according to the vendor (D120661 p. 2).

At a landfill site in Oregon, the cost of installing an Ecolotree cap was approximately $10,000 per acre. In contrast, the plastic liners that are typically used to cap landfills cost approximately $100,000 per acre (D20764H, p. 2).

The Oregon Department of Environmental Quality (DEQ) in conjunction with CH2M Hill of Portland, Oregon, designed a phytoremediation database that lists cost information for phytoremediation projects in Oregon. Estimated costs for the 14.3-acre Ecolotree cap used at Riverbend Landfill in McMinville, Oregon, were $45,000 for tree planting, $35,000 to $80,000 for monitoring, and $28,000 for irrigation. This application was slightly different than other landfill caps in that landfill leachate is applied directly to the poplars for remediation (D19710Y, p. 7).

Because phytoremediation utilizes solar energy, the technology requires few energy inputs. This factor reduces operating costs. In addition, expenses are spread out over a greater time period than other technologies since phytoremediation is a slower treatment process. The result is lower annual costs. Frick et al. also note that "agronomic costs, including planting, tillage, fertilization, and harvesting, can be insignificant in comparison with associated administrative costs, such as site management, regulatory reporting, and analysis of data" (D20756H, pp. 42, 43).

Information Sources

D120661, Great Plains/Rocky Mountain Hazardous Substance Research Center web page, October 1995

D133517, Schnoor et al., 1995

D19710Y, Oregon DEQ, 1999

D20756H, Frick et al., 1999

D20764H, People, undated

T0228

ECO-TEC, Inc.

EnviroMech Gold Biocatalytic Contaminant Degradation

Abstract

ECO-TEC, Inc., has developed the EnviroMech Gold biocatalytic contaminant degradation (BCD) process, a nontoxic, nonflammable biocatalyst designed to accelerate natural biodegradation of organic contaminants in soil and groundwater. Targeted contaminants are soluble in BCD, and become suspended in a colloidal mass that dramatically increases surface area exposed to microorganisms. BCD can also be used to improve the performance of soil washing techniques. The system is designed for in situ applications, but can also be used in an ex situ treatment train.

ECO-TEC claims the following advantages of BCD:

- Enhances biodegradation of petroleum products and other organic waste contamination in soil, groundwater, or marine environments.

- Replaces standard bioremediation processes.
- Enhances landfarming operations.
- Allows for in situ remediation in areas where it was previously considered ineffective (can be used under structures, in aquifers, and on bodies of water).
- Enhances the effectiveness of soil washing or filtration techniques by suspension of targeted contaminants in aqueous solutions and subsequent biodegradation.

BCD effectiveness is limited by the availability of oxygen, a specific range of temperatures, and the availability of moisture.

Technology Cost

According to information supplied by the vendor, treatment of wastes using EnviroMech Gold BCD technology in 1995 were estimated at \$28 to \$32 per ton of waste treated. Data listed as affecting process costs (in descending order) are characteristics of the soil, temperature, target contaminant concentration, depth of contamination, initial contaminant concentration, waste handling and preprocessing, quantity of waste, depth to groundwater, site preparation, labor rates, amount of debris associated with wastes, and the moisture content of the soil. The price estimate may not include all indirect costs associated with treatment (D10152Q, p. 33).

In the cleanup of 850 yd^3 of soil contaminated with diesel fuel from a gas station in Snoqualmie, Washington, costs were estimated at \$38.82/yd^3 of waste treated. In the remediation of a gasoline service station in Bellevue, Washington, 300 yd^3 of soil contaminated with gasoline and diesel were remediated using BCD at an estimated cost of \$43.33/yd^3. At this site a subsurface oxygen supply was installed in the treatment area prior to soil loading. The soil on site was saturated with water (D10152Q).

In the remediation of soil and sediment at the King County Public Works Compound (Sea Tac, Washington), 2000 yd^3 of material contaminated with heavy waste oil were remediated at an estimated cost of \$45.00/yd^3.

Another site remediated using BCD technology was located in Tacoma, Washington. During this application, 3750 yd^3 of soil were treated to a depth of 14 ft. The site was contaminated with gasoline, benzene, ethylbenzene, toluene, xylene, and diesel fuel. Remediation costs were estimated at \$49.85/yd^3 (D10152Q).

At a site in Monroe, Washington, 2600 yd^3 of gasoline-contaminated soil were treated to a depth of 16 ft. Costs were estimated at \$23.00/yd^3 (D10152Q).

Information Source

D10152Q, VISITT 4.0, 1995

T0229

Edenspace Systems Corporation

Hyperaccumulation of Metals

Abstract

In June of 1999, Edenspace Systems Corporation acquired Phytotech, Inc., a company specializing in phytoremediation technologies. Phytotech has developed several proprietary techniques for the phytoremediation of sites contaminated with heavy metals and radionuclides. Phytoremediation is an emerging bioremediation technology that uses plants to remediate contaminated media. Hyperaccumulation is a specific type of phytoremediation that can be used at sites contaminated by radionuclides and heavy metals. Hyperaccumulation may be defined as the ability

of a plant to take up and store more than 2.5% of its dry weight in heavy metals. In most cases, plants store metals in their above-surface biomass.

Phytotech also developed a related technology, called rhizofiltration, that uses adsorption by plant roots to remove metals from aqueous waste streams. This process involves the use of hydroponically grown plants to filter out targeted contaminants. Both technologies are commercially available through Edenspace.

Phytoremediation has the following advantages:

- Technology involves minimal site disturbance.
- Because the process is driven by solar energy, few energy inputs are required.
- Technology is more cost-effective for treating large areas than alternative technologies.
- Several plant species can be used simultaneously to treat a variety of contaminants at a given site.
- Process involves basic agricultural techniques.
- Technology has a high level of public acceptance.

Phytoremediation is only effective at shallow depths because root density decreases with depth. The mobility of contaminants also decreases with depth. In addition, phytoremediation is a slower process than some alternative technologies, and cleanup often requires several growing seasons. Environmental factors, including soil type, water availability, temperature, nutrients, and solar radiation can also limit the success of phytoremediation.

Technology Cost

According to the Interstate Technology and Regulatory Cooperation (ITRC) Work Group, Edenspace's phytoremediation technology was applied at a site in Trenton, New Jersey, for approximately $150,000. This project, which was part of the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) program, involved treating over one acre of lead-contaminated soil. Soil was treated to a depth of 12 inches (D22474I, p. D-3; D18278Z, p. 422).

Edenspace's phytoremediation technology was also used at a Daimler Chrysler facility in Detroit, Michigan, to reduce lead concentrations in 5700 yd^3 of soil (D19875I, p. 1). According to the vendor, initial lead concentrations in soils ranged from 75 to 3490 mg/kg. Final concentrations of 900 mg/kg were achieved after one growing season (D225138, pp. 12,13). Technology costs were reported to be $400,000, representing cost savings of approximately $1 million over alternative treatment methods (D22517C, p. 1).

According to an article published by the National Wildlife Federation, Edenspace's phytoextraction method removed uranium at the Aberdeen Proving Ground for one-tenth the cost of traditional treatment technologies. These traditional technologies were reported to be as high as $1 million per acre (D22515A, p. 2).

The U.S. EPA claims that the 30-year cost of treating lead at a 12-acre site using a phytoextraction technology would cost approximately $200,000. In contrast, the EPA estimated that excavation and disposal would cost $12,000,000, soil washing would cost $6,300,000, and soil capping would cost $600,000. For a 1-acre site with thick sandy loam, phytoextraction technologies are estimated to cost between $60,000 and $100,000. This estimate assumes treatment to a depth of 20 inches (D21292A, p. 17).

Phytotech states that rhizofiltration of aqueous wastes contaminated with toxic elements using sunflowers would average $2 to $6 per 1000 gal of waste treated, including disposal costs (D193924, p. 1). The vendor also claims that phytoremediation costs 15 to 25% less than alternative methods used to treat sites contaminated with lead (D19877K, p. 1).

In general, phytoremediation costs are dependent on treatment strategy. For example, harvesting plants that bioaccumulate metals can drive up the cost of treatment compared with techniques that do not require harvesting (D177815, p. 24).

Because phytoremediation utilizes solar energy, the technology requires few energy inputs. This factor reduces operating costs. In addition, expenses are spread out over a greater time period than other technologies since phytoremediation is a slower treatment process. The result is lower annual costs. Frick et al. also note that "agronomic costs, including planting, tillage, fertilization, and harvesting, can be insignificant in comparison with associated administrative costs, such as site management, regulatory reporting, and analysis of data" (D20756H, pp. 42, 43).

Information Sources

D177815, U.S. EPA, 1997
D18278Z, Flathman and Lanza, 1998
D193957, InSCIght, November 1997
D193924, Wilke, 1997
D19877K, Edenspace, undated web site
D20756H, Frick et al., 1999
D21292A, U.S. EPA, 2000
D22474I, ITRC, 2001
D225138, Blaylock, 2000
D22515A, Bower, 2000
D22517C, Helman, 2001

T0230

EET Corporation

Microwaste Waste Solidification

Abstract

Microwave solidification is an ex situ mixed-waste treatment process. The process is applicable for homogeneous, wet or dry, inorganic solids. The process dries the waste, mixes it with a matrix modifier, transfers it to a processing container, and subjects the mixture to microwave energy to melt the materials. The processed waste form then cools and solidifies to form crystalline mineral analogs.

This technology has been bench-, pilot-, and demonstration-scale tested. This technology is not currently commercially available.

The Microwaste™ process is not applicable to strictly organic wastes including organic liquids or wastes that are contaminated only with organic materials. The process would not be adversely affected by the presence of organic contamination but would require additional off-gas treatment to account for them. Radioactive or heavy metals with relatively low boiling temperatures, such as ruthenium and mercury, may also volatilize depending on the melting temperature of the waste media. This process is best used on an inorganic media, such as soil, ash, or precipitation sludge, that are contaminated with characteristic or listed hazardous metals.

This thermal process is listed under vitrification and can accept waste formulations that are vitreous in nature; however, due to the mode of operation and the inherent interaction between the microwave energy and the molten waste, the conditions produced in the process are conducive to crystal formation. Therefore, production of a strictly vitreous final waste form is not likely.

Technology Cost

An economic analysis was performed to compare the costs associated with four methods of sludge immobilization for treatment of wastes at the U.S. Department of Energy's (DOE) Rocky

TABLE 1 Cost Analysis Comparing Portland Cement/Diatomite Mixtures, Microwave Solidification, Cementation with Portland Cement, and Polyethylene Solidification

Cost Parameter	Portland Cement/Diatomite Mixture Costs (Dollars)	Cementation Costs (Dollars)	Polyethylene Solidification Costs (Dollars)	Microwave Solidification Costs (Dollars)
Cement	13,410	8,110	—	—
Diatomite	26,826	—	—	8,110
Polyethylene	—	—	24,320	—
Drums	59,760	27,600	27,360	20,140
Shipping	355,710	164,290	102,860	75,710
Storage	2,205,900	1,018,790	637,850	469,530
Total cost	2,661,610	1,218,790	792,390	573,490
Cost reduction per pound of sludge	—	8.07	10.45	11.68

Source: From D13539H, Petersen and Springer, 1993.

Flats plant. All of the methods studied eliminated the potential for free liquids and excessive amounts of particulate. The methods included: (1) addition of a Portland cement/diatomite mixture, (2) solidification using microwave technology, (3) cementation with Portland cement, and (4) polyethylene solidification. All costs were based on a production rate of 178,840 lb of wet sludge per year. The cost reduction (dollars per pound of sludge) relative to Portland cement/diatomite was $11.68 (1993 dollars) for microwave solidification, $10.45 (1993 dollars) for polyethylene solidification, and $8.07 (1993 dollars) for cementation. Table 1 gives a breakdown of these costs (D13539H, p. 8).

Information Source

D13539H, Petersen and Springer, 1993

T0231

EFX Systems, Inc.

Granular Activated Carbon–Fluidized-Bed Reactor (GAC–FBR) Process

Abstract

The granular activated carbon–fluidized-bed reactor (GAC–FBR) process is a commercially available, ex situ technology for the treatment of groundwater, wastewater, and process water contaminated with hydrocarbons and other organic pollutants. The GAC–FBR system combines the advantages of biological and physical treatment in a single unit operation, by employing GAC as the solid support for biofilm growth in a fluidized-bed reactor. Aqueous waste streams containing organic contaminants such as benzene, toluene, ethylbenzene, and xylenes (BTEX) and polycyclic aromatic hydrocarbons (PAHs) can be treated with this technology.

Liquid-phase adsorption using GAC is one of the most widely used remediation technologies. The major disadvantage of this approach is that it simply transfers contaminants from one phase to another, and further treatment or disposal of the receiving phase is typically required. Biological treatment has the potential to completely destroy contaminants, and it is generally

TABLE 1 Costs of GAC–FBR Biotreatment for Various Waste Streams

Influent Characteristics				Yearly Operating Costs			
Flow (gpm)	BTEX (ppm)	COD (ppm)	Capital Costs	Power	Carbon	Oxygen	Total Cost per 1000 Gal Treated
30	10	31	$125,000	$1,307	$16	$168	$1.68
100	10	31	$180,000	$5,227	$113	$559	$0.80
100	25	78	$280,000	$8,716	$201	$1,338	$1.26
1850	10	31	$750,000	$25,645	$1,188	$10,337	$0.19

Source: D17212D.

less expensive than physical–chemical treatment processes. Biological treatment, however, has conventionally been followed by GAC adsorption for effluent polishing and to provide backup treatment in the event of biological system failure. The GAC–FBR process combines the adsorptive capacity of GAC with the degradative ability of biological treatment to destroy organic contaminants and remove inorganics from aqueous waste streams.

The vendor cites the following advantages of the GAC–FBR system: a large surface area for biomass attachment; high biomass concentrations and the ability to control and optimize biofilm thickness; minimal plugging or channeling; no off-gas production; low hydraulic retention times; biomass carrier can be tailored to optimize system performance; and skid-mounted units with small footprints are available for most applications.

Technology Cost

The cost of GAC–FBR technology was compared with the cost of air stripping in 1995. Capital and operating costs on an annual basis were projected to be $72,200 for the GAC–FBR system, a cost less than 30% of the $252,000 projected for the air stripping system (D130392, p. 5).

According to the vendor, economic analyses of field demonstrations indicate that operation and maintenance (O & M) expenses of the GAC–FBR process averaged $0.071 per 1000 gal treated over a 6-year period. Comparatively, liquid-phase GAC adsorption and air stripping with vapor-phase GAC adsorption had O & M costs of $0.409 and $0.203 per 1000 gal, respectively (D15743R).

Vendor-supplied cost information covering typical system costs is available in Table 1.

Information Sources

D15743R, EFX Systems, Inc., 1996

D130392, Hickey et al., December 1995

T0232

Eichrom Industries, Inc.

Diphonix

Abstract

Eichrom Industries, Inc. (Eichrom), has developed Diphonix™ (diphosphonic ion exchange) technology, a multifunctional chelating ion exchange resin that contains disphonic acid and sulfonic acid ligands. The resin is used in ion exchange columns to remove metals and radionuclides from waste solutions and soils. The technology is commercially available in a variety of mesh sizes.

The vendor claims that Diphonix resin rejects common elements in favor of targeted metal ions. Unlike conventional ion exchange technologies, Diphonix can operate in acidic conditions. Because of their selectivity, the vendor claims Diphonix resins can absorb greater amounts of targeted metals, reducing the volume of secondary waste to be treated and minimizing restrictions on the treated effluent. The resin bed can be regenerated in a manner similar to conventional resins.

The vendors state that data from bench- and pilot-scale evaluations of Diphonix resin should only be used as a general guide to applications of the technology to real-world applications. Each use of the technology will likely require site- and waste-specific evaluations before the initiation of treatment. Some metals (i.e., iron and aluminum) can interfere with the extraction of targeted radionuclides in mixed-waste applications.

Technology Cost

According to the vendor, Diphonix's affinity for actinide ions over more predominant cation species makes metal removal by ion exchange resins economically feasible. The resin produces a concentrated waste stream that reduces the total volume of waste requiring disposal (D20304T, p. 18).

As of April 1, 1999, the vendor sold 500 g of 50- to 100-mesh Diphonix resin for $505.00. The 100- to 200-mesh Diphonix resin sold for $525.00 per 500 g (D18897K, p. 5).

Information Sources

D18897K, Eichrom, 1999

D20304T, Totura, 1994

T0233

Ejector Systems, Inc.

VESTRIP

Abstract

VESTRIP™ is a system designed for the in situ treatment of soils contaminated with volatile organic compounds (VOCs); benzene, toluene, ethylbenzene, and xylenes (BTEX); and other contaminants that are amenable to soil vapor extraction (SVE). The vendor, Ejector Systems, Inc. (ESI) has combined the key components of SVE systems with an air stripper to form a product that performs the functions of both. The name, "VESTRIP," is a contraction of VES (vapor extraction system) and air stripping.

According to ESI, several VESTRIP units have been built and successfully tested. ESI has also applied for a U.S. patent for the VESTRIP technology. This technology is currently commercially available.

Advantages of SVE-based technologies often include:

- Minimize site disturbance.
- Treat large volumes of soil.
- Install quickly and easily at most sites.
- Reduce VOCs in the vadose zone of the soil, decreasing the potential for contaminant migration.
- Complement groundwater treatment systems.

Limitations of SVE-based technologies often include:

- Subsurface heterogeneity can interfere with uniform airflow.
- Site permeability, clay content, depth to water table, and organic content can impact technology performance.

- Extracted vapors will often require the use of a treatment technology.
- Technologies may not be able to meet soil cleanup criteria.

Technology Cost

According to the vendor, the initial cost of the VESTRIP system will be significantly less than if the SVE system and an air stripper were purchased separately. Due to the fact that it uses one blower instead of two, its energy consumption is also expected to be lower (personal communication, Susan Hyman, 1997).

Both SVE and air stripping systems are designed to remove volatile organic contaminants (VOCs). Since VESTRIP does not destroy contaminants, it is most commonly used in a treatment train with other technologies such as granular activated carbon (GAC), thermal oxidation technologies, or scrubbing. Other technologies, including bioremediation, natural attenuation, air sparging, or fracturing may be used to either increase the efficiency of the technology or treat residual contamination that may remain after it is used at a site. All of these factors will impact treatment costs (D22449H, p. 4-1).

Many site-specific factors can influence the cost of VESTRIP treatment. Soil properties that can influence the cost of any SVE system include permeability, porosity, depth and stratigraphy of the contamination, site heterogeneity, and seasonal water table fluctuations. In general, the more permeable and homogenous the soil, the more efficiently any SVE will operate, and the lower treatment costs will be (D22449H, p. 4-4).

Contaminant properties can also affect treatment costs. The type and amount of contaminants will impact the efficiency of any SVE technology. These impacts include the number of extraction wells, the power of the blower unit, and the length of operation required to achieve project goals. Contaminant properties will also impact the type of ancillary technology(ies) selected (D22449H, p. 4-4).

Information Source

D22449H, U.S. EPA, 2001

T0234

Ejector Systems, Inc.

Stripperator

Abstract

The Stripperator is an ex situ technology for the treatment of hydrocarbon-contaminated groundwater. It integrates an oil/water separator, an air stripper, a sump, and a blower into one unit. According to the vendor, the technology will separate free product, coalesce suspended or colloidal hydrocarbons, settle solids, and remove 99.99% of dissolved volatile organic compounds (VOCs).

The vendor claims the following advantages for this technology:

- No extra tanks, pumps, or pipes are needed.
- Components are easily accessible and the system is simple to maintain.
- System allows for quick inspection and viewing of operation in progress.
- Process eliminates repumping, sumps, and controls.
- Leak-free indoor installation of the system is possible.
- Vibration of the unit is minimal.

When processing groundwater with high metals content and/or high total dissolved solids (TDS), additional treatment technologies (e.g., ion exchange) will be required.

Technology Cost
The Stripperator was used as part of a pump-and-treat system installed at Camp Lejeune in North Carolina. This system, which was used to remove VOCs, had an average cost of $95,000 per pound of contaminant removed. According to the U.S. Navy, $175,000 was spent on the system to remove 3 lb of contaminants, and $325,000 was spent to remove an additional 0.5 lb. The Navy claims that the high cost of treatment at the site resulted from inefficiencies in groundwater extraction methods and was not caused by the use of the Stripperator (D22770N, p. ES-1, ES-3, 3-18–3-28).

Information Source

D22770N, Department of the Navy, 2000

T0235

Electrochemical Treatment of Contaminated Groundwater — General

Abstract
The electrochemical treatment of contaminated groundwater technology uses direct electrical current applied between two immersed electrodes to produce oxidation–reduction reactions in aqueous solutions. Positively charged metal ions are attracted to the negatively charged electrode (the cathode), where they are reduced.

The process can be used to treat dissolved metals and is commonly used in groundwater treatment for the reduction and precipitation of hexavalent chromium, as well as in the oxidation of cyanide wastes (at concentrations up to 10%). Other potential applications of electrochemical treatment include remediation of arsenic, cadmium, molybdenum, aluminum, zinc, and copper ions.

Electrochemical treatment has been used for many years in the mining and utility industries and is a proven technology for removing hexavalent chromium from wastewater.

Both batch and continuous-flow electrochemical reactors are commercially available.

Technology Cost
In electrochemical treatment of extracted groundwater, the operating costs for electrode consumption, power, and acid for the electrochemical unit are estimated at approximately 10 cents per 1000 gal of groundwater treated. At an anticipated flow rate of 20 gal/min (gpm), the operating costs are approximately $1000 annually. Labor and waste disposal costs for the electrochemical treatment process are estimated to be approximately $50 per day (D168869, p. 7–14).

At the Coast Wood Preserving, Inc., Superfund site (Ukiah, California), the technology was used to remove metal contamination to comply with both state and federal cleanup standards [50 parts per billion (ppb) arsenic, 50 ppb chromium, and 1 ppm copper]. The estimated total cost for the source control component of the remedy was $1,000,000, and the estimated total operational and maintenance costs was estimated to be $19,500 for a 20-year period (D16888B, p. 3, Report Documentation p. 2).

Table 1 shows treatment costs for the technology (based on a processing rate of 20 gpm) in comparison to other groundwater treatment technologies (i.e., chemical reduction and precipitation, chemical precipitation with sedimentation or filtration, activated carbon adsorption, ion exchange, reverse osmosis, and electrodialysis) (D168869, Table 13).

Information Sources

D168869, EPA Remedial Action Plan, September 1989

D16888B, EPA (Record of Decision for Coast Wood Preserving Superfund site), September 1989

TABLE 1 Comparisons of Costs for Groundwater Treatment Technologies (D168869, Table 13)

Technology	Installation Comparisons	Probable Cost ($) Based on 20 gpm Capital	(O & M)[a]	Comments
Electrochemical process	Relies on proven technology	Low	19,500	By far the most effective technique for removing Cr(VI) from groundwater; depletes Cr(VI) content of ground water to EPA compatible level.
Chemical reduction and precipitation	Relies on proven technology	224,000	192,000	This process generates a large volume of sludge must be pretreated and disposed.
Chemical precipitation with sedimentation or filtration	Relies on proven technology; limited installation for chromium removal	192,000	64,000	Effectiveness limited; low removal efficiencies are reported in literature.
Activated carbon adsorption	Relies on proven technology	50,000	328,000	Effectiveness limited.
Ion exchange	Relies on proven technology	84,000	14,000	High regeneration cost; fluctuating effluent quality.
Reverse osmosis	Relies on proven technology	400,000	150,000	Generates a concentrated stream, 10 to 25% of the feed volume, which must be treated further by secondary treatment and high cost.
Electrodialysis	Relies on proven technology	85,000	11,000	Membrane fouling and clogging by residual colloidal organic matter in groundwater; may require more skill and care than other systems discussed in this application.

[a] O & M, operational and maintenance.

T0236

Electrokinetic Remediation — General

Abstract
Electrokinetic remediation is a commercially available, in situ technology for the treatment of soil and groundwater contaminated with heavy metals, radionuclides, and organic contaminants. The technology employs a low-intensity direct electrical current to desorb and remove ionic and polar organic contaminants from the subsurface. The current is applied across electrode pairs that have been implanted in the ground on either side of the contaminated zone. Surfactants and/or complexing agents may be introduced at the electrodes to enhance contaminant removal rates.

According to the Interstate Technology and Regulatory Cooperation (ITRC) Work Group and the Ground-Water Remediation Technologies Analysis Center, the Electrokinetic Soil Cleaning technology has the following advantages:

- May be able to treat soils not accessible for excavation.
- Mobilizes contaminants without adding acid or destroying the basic soil structure.
- Capable of removing heavy metals from unsaturated soils.
- Applicable in soils with low permeability and high clay content.
- Treats inorganic and organic contaminants.
- Is cost effective.

Electrokinetic remediation is limited by the type of contaminant, heterogeneities or anomalies in the soil, extreme pHs, pore water chemistry, lack of pore water, contaminant and noncontaminant ion concentrations, metals precipitation, and reduction–oxidation changes induced by the process electrode reactions. It may be difficult to estimate the time that will be required to remediate a site using this technology. Laboratory treatability testing may provide a false indication of the applicability of electrokinetic remediation at a specific site. Further research is required to determine the technology’s limitations and ramifications.

Technology Cost
According to the ITRC Work Group, the costs of electrokinetic remediation applications will vary based on the site’s specific chemical and hydraulic properties. The initial and target contaminant concentrations, concentrations of nontarget ions, conductivity of the pore water, soil characteristics and moisture content, the quantity of waste, depth of contamination, residual waste handling and processing, site preparation requirements, and electricity and labor rates have a significant effect on the unit price. The U.S. Army Environmental Center states that equipment, installation, maintenance, removal, and contaminant disposal costs can significantly increase the costs of using electrokinetic remediation for turnkey operations (D19938G, pp. 16, 17; D10137R, p. 24; D21596N, p. 9).

The Ground-Water Remediation Technologies Analysis Center (GWRTAC) estimated the direct energy costs of an electrokinetic remediation cell based on pilot-scale field studies with an energy consumption rate of 500 kWh/m^3 and an electrode spacing of 1 to 1.5 m. The estimated, direct energy costs for an electrokinetic remediation cell were approximately \$25/m^3 of soil or \$0.05/kWh of energy consumed. Total power consumption was directly proportional to the time required to meet cleanup goals (D21599Q, p. 8).

Technology-specific cost information is available in the RIMS database for the following technologies:

- Electrokinetic Decontamination Process by ISOTRON Corporation (T0430)
- Electroreclamation by Geokinetics International, Inc. (T0337)

- Lasagna by Monsanto Company (T0537)
- Electroremediation by Corrpro Companies, Inc. (T0185)
- Electrokinetic Soil Cleaning by Electrokinetics, Inc. (T0238)
- Electrokinetic Treatment by Electro-Petroleum, Inc. (T0239).

Information Sources

D10137R, VISITT 4.0, undated
D19938G, ITRC, 1997
D21596N, U.S. Army Environmental Center, 2000
D21599Q, Cauwenberghe, 1997

T0237

Electrokinetically Enhanced Bioremediation — General

Abstract

Electrokinetically enhanced bioremediation is an in situ process for the treatment of soils and groundwater contaminated with petroleum hydrocarbons and other compounds easily biodegraded under anaerobic conditions. Bench-scale tests have shown that the application of an electric field provides electrokinetic transport of nutrients and biodegrading bacteria to areas of contamination. In addition, microbial growth is enhanced, nitrate transport can be predicted, and beneficial temperature increases can be achieved to areas of contamination.

System failure for in situ bioremediation efforts is often the result of ineffective transport of nutrients and electron acceptors due to channeling into preferential flow paths, heterogeneities, adsorption, biological utilization, and/or chemical reactions in the soil. Many of these problems can be overcome using electric fields for transport and injection instead of conventional groundwater injection by hydraulic techniques.

Technology Cost

No available information.

T0238

Electrokinetics, Inc.

Electrokinetic Soil Cleaning

Abstract

The Electrokinetic soil cleaning process uses electrical current to physically separate contaminants from soils, sediments, groundwater, and sludges. The technology can also be used to deliver nutrients to contaminant-degrading microorganisms in the subsurface. This technology can be applied in situ or ex situ. Electrodes are placed on each side of the contaminated material, and direct current (DC) is applied. Contaminants move to the electrodes through electro-osmosis (the movement of water due to the application of DC electricity) or electromigration (the movement of ions or charged particles due to the application of DC electricity). Conditioning fluids may be added or circulated at the electrodes to improve process electrochemistry. The contaminants are electroplated on the electrodes or separated in a posttreatment unit.

Electrokinetic soil cleaning has been demonstrated during in situ pilot-scale studies. As of September 2001, Electrokinetics, Inc., is no longer in business. The Electrokinetic soil cleaning process is not commercially available.

According to the Interstate Technology and Regulatory Cooperation Work Group, the Electrokinetic soil cleaning technology has the following advantages:

- May be able to treat soils not accessible for excavation.
- Treats soils with low permeability and high clay content.
- Desorbs and mobilizes contaminants.
- Treats inorganic and organic contaminants.
- Remediates heavy-metal contamination in unsaturated soils.

It may be difficult to estimate the treatment time for Electrokinetic soil cleaning technology applications. Heterogeneities or anomalies in the soil will reduce removal efficiencies. Electrokinetic treatments are limited by the pH of the soil, the solubility of the contaminant, the desorption of the contaminants from the soil matrix, the amount of moisture in the soil, contaminant and nontarget ion concentrations, and reduction–oxidation changes induced by the electrode reactors. In bioremedial applications, concentrations of contaminants may be too high for indigenous or transplanted microbial populations to initiate degradation. Additionally, the bioremediation of contaminants may produce by-products that are toxic to the microbial community thus ceasing biodegradation processes.

Technology Cost

The total costs for using the Electrokinetic soil cleaning technology range from \$20 to \$100/yd^3 of treated media. The vendor estimated that the costs for an electrokinetically enhanced bioremediation project would range from \$10 to \$90/yd^3. The costs will vary based on the site's specific chemical and hydraulic properties. The unit price for this technology is dependent on:

- Initial and target contaminant concentrations
- Concentrations of nontarget ions
- Conductivity of the pore water
- Soil characteristics and moisture content
- Quantity of waste
- Depth of contamination
- Residual waste handling and processing
- Site preparation requirements
- Electricity and labor rates (D19939H, pp. 6, 7; D10137R, p. 24).

In 1996, the vendor stated that the results of pilot-scale studies using simulated soil samples indicated that the energy expenditures for the extraction of heavy metals from soils may be at least 500 kWh/m^3 at electrode spacings of 1.0 to 1.5 m. The direct cost of these studies suggests that the energy expenditure and enhancement costs for a full-scale application of the technology could be at least \$50/m^3 (D12897W, p. 183).

Energy cost for a 4-month pilot-scale test on a 2-ton kaolinite specimen contaminated with 2000 μg/g of lead was approximately \$15 per ton. Energy costs from the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program demonstration conducted in 1994 were approximately \$6 per ton per month (D12696P, p. 283).

Information Sources

D10137R, VISITT 4.0, undated

D12696P, U.S. EPA, 1995

D12897W, Acar et al., 1996

D19939H, GNET, undated

T0239

Electro-Petroleum, Inc.

Electrokinetic Treatment

Abstract
Electrokinetic soil treatment is a commercially available in situ technology for the removal of metals and organic compounds. The application of direct current (DC) in a porous medium leads to two transport mechanisms: electromigration and electro-osmosis. The combination of these two transport phenomena results in the movement of contaminant ions toward either the cathode or anode. Nonionic contaminants are transported by electro-osmosis alone.

Electrokinetic treatment can be used to remediate soils, sludges, and sediments contaminated with heavy metals and organic hydrocarbons. Electrokinetic treatment works well on clay-type soils with low hydraulic permeability, which are difficult to treat using other in situ technologies. Electrokinetic permeabilities for aqueous systems in clays have been demonstrated to be up to 1000 times greater than normal hydraulic permeabilities, and some heavy metals have exhibited removal efficiencies of up to 100%.

The electrokinetic process will be limited by the solubility of the contaminant and the desorption from the clay matrix that is contaminated. Heterogeneities or anomalies in the soil will reduce removal efficiencies. Extreme pHs at the electrodes and the may inhibit the system's effectiveness. Electrokinetic remediation is most efficient when the pore water has low salinity. The process requires sufficient pore water to transmit the electrical charge. Contaminant and noncontaminant concentrations effect the efficiency of the process.

Technology Cost
According to the Interstate Technology and Regulatory Cooperation Work Group, the cost of electrokinetic remediation is dependent on specific chemical and hydraulic properties of the soils present at the site. Initial and target contaminant concentrations, concentration of nontarget ions, conductivity of pore water, soil characteristics, moisture content, quantity of waste, depth of contamination, residual waste handling and processing, site preparation requirements, and electricity and labor rates also have a significant effect on the unit price of electrokinetic remediation (D19938G, pp. 16, 17; D10139T).

According to the vendor in 1997, treatment costs for the Electro-Petroleum, Inc., electrokinetic treatment range from \$60 to \$110/yd^3 of contaminated soil (D19938G, p. 16).

In 1995, the vendor estimated the cost of in situ remediation based on laboratory-scale experiments. The estimate was approximately \$50/yd^3 of soil treated (D126089, p. 12).

The cost of electrokinetic treatment is dependent on specific chemical and hydraulic properties present at the site. The total cost of remediation has been projected to be in the range of \$50 to \$150/yd^3 in 1991 or 1992 (D131624, p. 6).

Information Sources

D10139T, VISITT, July 1995

D126089, U.S. EPA, April 1995

D131624, U.S. DOE, June 1996

D19938G, Interstate Technology and Regulatory Cooperation Work Group, 1997

T0240

Electro-Pyrolysis, Inc.

DC Graphite Arc Furnace

Abstract
Electro-Pyrolysis, Inc. (EPI) has developed the direct current (DC) graphite arc furnace vitrification technology for the ex situ treatment of wastes. The arc furnace can be operated as an oxidation or reduction process. The vendor states that DC arc melter treatment produces a leach-resistant solid and reduces the volume of wastes that require disposal.

Arc melter remediation technology derives from the steel industry. Today, half of all steel in the United States is produced in an arc melter. EPI DC arc melters are offered for commercial design, sale, and installation by Svedala Pyro Systems.

According to researchers, arc melter systems can achieve higher temperatures than joule-heated vitrification units. Arc melter systems have a simplified design compared to arc plasma systems, which require water to cool the metal electrodes.

The DC arc process has several advantages over an alternating current (AC) arc furnace. An AC arc furnace requires three electrodes during operation, while a DC furnace only needs one. The DC system is considered "utility friendly" because it does not introduce a flicker into the utility system. In addition, EPI states that DC arc systems have lower electrode consumption, energy costs, and noise levels than AC systems.

According to researchers, limitations of DC arc systems include the corrosive nature of the vitrified material, limitations on salt and water content, and uncertain performance in the destruction of organic wastes. The addition of flux materials may be required to allow the vitrified material to be poured and to allow the final waste form to meet performance goals. Volatile radionuclides and metals may accumulate in the off-gas treatment system.

Technology Cost
In 1994, Pacific Northwest Laboratories (PNL) estimated that a DC arc melter manufactured by EPI, capable of treating 1.5 to 2 tons per hour would have a startup cost of approximately $2 million (D116154, p. 4).

In a 1994 U.S. Department of Energy (DOE) study on system benefits associated with high-temperature melters, Brown et al. reported that high-temperature systems allowed for higher mass loading, a more dense final waste form, and required a lower characterization frequency than lower-temperature joule melters. In an estimate based on the treatment of DOE mixed wastes, it was estimated that treating the wastes using a Joule melter system would cost $4.9 to $6.3 billion. It was estimated that using a high-temperature melter system could save up to $2.6 billion over the life of the project (D115515, p. 652).

Most of the cost data for vitrification technologies are estimates based on pilot-scale operations. Such data are suspect because they are based more on extrapolation than on experience. Cost estimates are difficult to compare because the assumptions on which they are based may vary widely (D18248T, p. 55).

Many site-specific characteristics have an impact on vitrification technologies. One critical aspect of any thermal technology is the water content of the waste. Water dilutes feed material, requires energy to drive off, and physically limits the feed rate of waste. Feed preparation is another variable, which differs with the technology and with site-specific characteristics. Many estimates do not take into account site preparation and waste disposal costs. Only complete treatment life-cycle assessments can provide reliable comparison data, and such studies are, by definition, highly site- and waste-specific (D18248T, p. 55).

Various sources estimate vitrification costs as ranging from under $100/ton to over $1000/ton for units treating hazardous waste. These estimates are assumed to be for treatment only, not including pretreatment and disposal costs. The extreme variability of the costs may be attributable to differences in feed type and water content of the waste (D18248T, p. 55).

In 1998, the DOE prepared a cost estimate of a 10-ton/day DC arc system. The system includes a furnace, waste feed system, off-gas treatment system, secondary combustion chamber, power supplies (arc power, glass overflow heating system, and metals drain), instrumentation, control systems, and product removal and handling systems. Site permitting costs and site preparation costs were also estimated (D207307). These estimates are summarized in Tables 1 and 2.

Information Sources

D115424, Steele and Mayberry, 1994

D115515, Brown et al., 1994

D18248T, Sigmon and Skorska, 1998

D207307, U.S. DOE, 1998

TABLE 1 Estimated Capital Cost for DC Graphite Arc Furnace System

Component	Price
Furnace system	$3,092,000
Off-gas treatment system	$370,000
Secondary combustion chamber	$605,000
System design	$687,000
Total system costs	$4,754,000
Facility/site prep costs	$20,000,000
Facility cost	$2,000,000
Site preparation	$5,000,000
Total facility/site/permitting costs	$27,000,000
Total costs	$31,754,000

Source: Adapted from D207307.

TABLE 2 Estimated Operating Cost for DC Graphite Arc Furnace System

Component	Cost per Ton
Capital cost contribution	$734
Operating power	$99
Operating labor	$1,440
System maintenance	$11
DC electrode replacement	$100
Overflow heater replacement	$8
Nitrogen use	$11
Off-gas blowdown disposal	$6
Glass formers and additives	$14
Total operating costs	$1,689
Final waste form product disposal	$2,245
Total costs to install and operate	$4,668

Source: Adapted from D207307.

T0241

Elf Atochem of North America, Inc.

Inipol EAP-22

Abstract
Inipol EAP-22 is an oleophilic (oil-preferring) fertilizer that is applied to oil spills and hydrocarbon-contaminated sediments, soils, or sludges in order to stimulate bioremediation. Hydrocarbon biodegradation is limited in nature by temperature and the availability of oxygen, nitrogen, and phosphorus. Most oil spills occur on the water or land surface. In these situations, oxygen is not a limiting factor. The fertilizer Inipol EAP-22 increases the rate of natural biodegradation by providing nitrogen and phosphorus to hydrocarbon-degrading microbes. The technology has been demonstrated in full-scale bioremediation projects and is commercially available.

According to the vendor, Inipol EAP-22 has several advantages:

- Optimizes ratio between carbon, nitrogen, and phosphorus.
- Releases nutrients over time.
- Inhibits the formation of water-in-oil emulsions.
- Is completely biodegradable.

The toxicity of the Inipol EAP-22 microemulsion is controversial. The vendor claims that the microemulsion has no toxicity for flora and fauna. The material safety data sheet (MSDS) for Inipol EAP-22 indicate that 2-butoxyethanol is the most toxic compound in the fertilizer. The compound is an eye, skin, and respiratory irritant that can be absorbed through the skin.

The technology is not applicable in shallow-water, poorly flushed, restricted embayments where nutrient overloading may cause algal blooms. The fertilizer does not stimulate bioremediation if oxygen is a limiting factor for biodegradation. The microemulsion does not treat sites with large clusters of oil, which must be dispersed before the Inipol EAP-22 application. Tidal activity increases the effective depth of the fertilizer. At sites with low tidal activity, the treatment depth will be shallow. Inipol EAP-22 is not effective on fine-grained sediments.

Technology Cost
No specific cost information is available for Inipol EAP-22's most common usages (coarse-grained sediments or sludges). In 1994, the U.S. Department of Energy (DOE) evaluated the microemulsion's cost-effectiveness for the treatment of soils. Researchers used bench-scale tests to compare Inipol EAP-22 with inorganic fertilizers. Although the Inipol EAP-22 was more effective than the inorganic fertilizers, the DOE determined that it was not cost effective to use the oleophilic fertilizer for the treatment of soils because Inipol EAP-22 was more expensive and more difficult to apply (D214095; D214142).

Information Sources

D214095, University of Georgia, Savannah River Ecology Laboratory, 1994

D214142, University of Georgia, Savannah River Ecology Laboratory, 1994

T0242

ELI Eco Logic International, Inc.

Gas-Phase Chemical Reduction Process

Abstract
The Eco Logic gas-phase chemical reduction (GPCR) process uses hydrogen and temperatures of 850°C or higher to destroy hazardous organic wastes at near-ambient pressure. The GPCR

process can be used to treat contaminated soils and liquid wastes containing polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), chlorinated dioxins and dibenzofurans, chlorinated solvents, chlorobenzenes, and chlorophenols. Chlorinated hydrocarbons, such as PCBs and polychlorinated dibenzo-*p*-dioxins are converted to methane and hydrogen chloride (HCl). Nonchlorinated organic compounds, such as PAHs, are reduced to lighter hydrocarbons like methane and ethene. The reformed gas is treated with a scrubber to remove hydrogen chloride and particulates.

The GPCR process is commercially available as a fixed-facility, full-scale system; a semi-mobile model; and a portable demonstration unit. The technology has been used in full-scale cleanups.

According to the vendor, the GPCR process has the following advantages:

- Closed-loop operation with no uncontrolled emissions
- High degree of internal waste recycle
- Complete destruction of principle organic contaminants without the production of dioxin and dibenzofuran.

Other limitations include the following:

- Feed soils need to be screened or crushed to less than 2.5 cm in diameter.
- Storage and handling of hydrogen presents potential fire and explosion hazards.
- Solids could accumulate in the reactor and cause plugging.
- Process can only treat organics in the gas phase.
- System can encounter operating difficulties in cold climates.

Technology Cost

Based on data from the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration program, the cost for using this technology to treat liquid wastes was calculated. Treatment costs vary with the system utilization rates. These cost estimates were \$2000 per ton (1994 U.S. dollars) for a utilization rate of 60%; \$1850 per ton for a rate of 70%; and \$1670 per ton for a rate of 80%. The site preparation cost was \$127,400. The feed rates used for this analysis were assumed to be 2.2 kg/min of wastewater and 0.485 kg/min of waste oil. The waste streams were simultaneously injected into the reactor. Labor proved to be the most important element affecting cost (52%), followed by site preparation (15%), supplies (12%), and startup/mobilization (12%) (D187160, p. 19).

This cost estimate included the following parameters:

- Site preparation
- Capital equipment
- Startup/mobilization
- Labor
- Supplies
- Utilities
- Transportation and disposal of residuals
- Maintenance costs
- Demobilization (D128029, pp. 19, 22, 24)

For a commercial application, the estimated capital costs were \$585,000. The estimated cost of treating contaminated soil was \$695 per ton for a 60% utilization factor and \$550 per ton for a 80% utilization factor. Fuel costs accounted for 67% of the cost estimate. Equipment and labor costs composed 11 and 9% of the estimate, respectively (D187160, p. 19).

Certain cost items that were site specific, project specific, or the responsibilities of the site owner/responsible party were excluded from the estimate. These include the following:

- Project engineering and design, specifications, and requisitions
- Permits, regulatory requirements, plans
- Wells, pipelines, excavation/stockpiling/handling of waste (excluding feed to process equipment)
- Backfilling, landscaping, and any major site restoration
- Sampling and chemical analysis except as required for disposal of miscellaneous effluents and wastes
- Initiation of monitoring programs
- Posttreatment reports, regulatory compliance (D128029, p. 20)

A pilot-scale demonstration remediating harbor sediment was conducted 1 year before the SITE demonstration. Based on the pilot-scale demonstration, the processing costs for a full-scale, 110-ton/day unit were projected to be \$230/ton (September 1992 U.S. dollars). It is assumed that the unit will be down approximately 30% of the time for maintenance and design improvements in the first year of operation. Based on this system availability, 28,105 tons can be processed in one year. This cost included estimates for variable costs, fixed costs, and depreciation/insurance. Variable costs include diesel fuel for a mobile generator, hydrogen, and caustic. Fixed costs include labor; diesel fuel for pumps, heaters, process equipment, and instrumentation; propane, water and sewer; and parts and supplies. Depreciation/insurance costs include capital cost depreciated over a 3-year period, general insurance costs, and pollution liability insurance. This analysis does not include costs for setup and demobilization (D128007, pp. 5.12–5.14).

The U.S. Department of Energy estimated that the gas-phase chemical reduction process would cost \$400/ton to treat soils and \$2000/ton to treat liquid waste composed of 100% PCBs (D22124Z, p. 18).

Information Sources

D128007, Anderson, 1994
D128029, U.S. EPA, 1994
D187160, U.S. EPA, 1998
D22124Z, Costner et al., 1998

T0243

EM & C Engineering Associates

Chemclood

Abstract

Chemclood is a commercially available technology for the treatment of waste battery sites. Whole or broken batteries are typically sent off-site to separate the lead, plastic, and battery paste. The Chemclood process can provide potential profits from recovered lead and plastic, which can be recycled and sold.

All information is from the vendor and has not been independently verified.

Technology Cost

The vendor estimates the cost of remediation using Chemclood to range from $0.01 to $5.00/gal of waste treated. Initial and target contaminant concentrations and quantity of waste to be treated have the most significant effect on the cost of remediation (D10133N, p. 8).

Information Source

D10133N, VISITT, July 1995

T0244

EM & C Engineering Associates

Extra Pure

Abstract

The Extra Pure process uses an unspecified solvent to extract organic contaminants from various wastes. The organics are separated from the solvent by distillation. The technology can be used for liquids, sludges, solids, or any mixture with a wide range of organics.

The process is limited to organic compounds, and removal of organic compounds is incomplete in some cases. RIMS was unable to verify the development or use of this technology. All information is from the vendor and has not been independently verified.

Technology Cost

The vendor estimates treatment with Extra Pure to cost between $20 and $100/yd^3 yard of waste treated. Initial and target contaminant levels and the quantity of waste to be treated have the most significant effect on the cost of the technology (D10132M, p. 8).

Information Source

D10132M, VISITT, July 1995

T0245

EM & C Engineering Associates

Grid Injection

Abstract

Grid injection is a commercially available, in situ technology for the treatment of soils contaminated with organic compounds. The technology injects steam to vaporize volatiles and drive out nonvolatiles in a fashion similar to steam stripping.

All information is from the vendor and has not been independently verified.

Technology Cost

In 1995 the vendor estimated the cost of treating soil with grid injection to range from $30 to $80 per ton. Initial and target contaminant levels and the quantity of waste to be treated have the most significant effect on the cost of the technology (D10131L, p. 8).

Information Source

D10131L, VISITT, July 1995

T0246

EM & C Engineering Associates

Vitriflux

Abstract
EM & C Engineering Associates markets the Vitriflux™ vitrification system for the treatment of hazardous wastes. The vendor claims that the unique feature of this vitrification system is that fluxing material is added to achieve vitrification at relatively low temperatures. Although this technology has only been tested as an ex situ process, the developer claims that in situ treatment is possible.

All information included in this summary was provided by the vendor and has not been independently verified.

Technology Cost
In 1995, EM & C Engineering Associates estimated the cost of processing contaminated waste using the Vitriflux vitrification system would range from \$40 to \$100 per ton. This estimate did not include all indirect costs associated with treatment, such as excavation, permits, and treatment of residuals. Factors listed as having a primary effect on costs include initial contaminant concentration, moisture content of the soil, the target contaminant concentration, waste handling and preprocessing costs, and the quantity of waste treated. Factors listed as having a secondary effect on costs include characteristics of the soil, characteristics of the residual wastes, site preparation costs, depth of contamination, and depth to groundwater. Factors with lesser impacts on treatment costs include utility/fuel rates, labor rates, flue gas compositions, and the amount of debris associated with the wastes (D10130K, p. 8).

Information Source

D10130K, VISITT 4.0, 1995

T0247

Emerging Energy Marketing Firm, Inc.

Low-Energy Transmutation

Abstract
Emerging Energy Marketing Firm, Inc. (formerly known as Trenergy, Inc.) is developing a technology that causes low-energy transmutation of radioactive wastes by using acceleration of combined charge clusters. According to the vendor, radioactive thorium can be stabilized with less than 5000 V of electricity.

The vendor claims that this technology will have four basic applications: (1) on-site stabilization of high-level liquid radioactive waste; (2) development of cheaper thermal and electrical energy sources; (3) creation of scarce elements from more plentiful elements; and (4) design and fabrication of table-top particle accelerators.

This technology is still at small scale and is commercially available from authorized distributors. All information contained herein was provided by the vendor and has not been independently verified.

Technology Cost
The low-energy transmutation kit is available through authorized distributors for a cost of \$3000. This includes: (1) a closed-cell electrolyte chamber; (2) a power supply; (3) technical assistance;

(4) one-year subscriptions to *Infinite Energy*, *New Energy News*, and *Journal of New Energy*; and (5) a money-back guarantee (D17644X, p. 1).

Information Source

D17644X, Fusion Information Center, date unknown

T0248

Energia, Inc.

Reductive Photo-Thermal (RPT) Technologies

Abstract

Energia offers a group of remediation technologies collectively called reductive photo-thermal (RPT) technologies. These technologies are used to remediate off-gas waste streams containing chlorinated hydrocarbons. Reductive photo-dechlorination (RPD) is based on the synergistic effect that occurs when ultraviolet (UV) light reacts with contaminants in a reducing atmosphere at temperatures less than 500°C. The result of this effect is a conversion of chlorinated hydrocarbon contaminants into hydrocarbons. The UV light promotes carbon–chlorine bond cleavage and long-chain radical reactions.

Two processes have evolved from the RPD process: reductive thermal oxidation (RTO) and reductive photo-thermal oxidation (RPTO). Each process converts chlorinated hydrocarbons into simple hydrocarbons, carbon monoxide, carbon dioxide, and hydrochloric acid. Whereas heat drives the RTO treatment process, both heat and UV light drive the RPTO process.

The RPD technology was accepted in the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) Emerging Technology Program in summer 1992. Since then, this technology has completed the bench-scale developmental stage, and a pilot-scale demonstration of the technology was scheduled for 1999. The technology is not commercially available.

RPT technologies are designed to treat volatile chlorinated wastes in liquid, gaseous, or adsorbed state. Suggested applications include treatment of organic wastes, treatment of discharge from soil venting operations, and destruction of contaminants released during the regeneration of saturated activated carbon. Energia claims that the technologies can be used as primary treatment for gas streams containing chlorinated hydrocarbons or to pretreat gas streams entering catalytic oxidation systems by reducing chlorine content and protecting the catalyst against poisoning. According to the vendor, the technology has several advantages. RPT is relatively inexpensive, is operated at low to moderate temperatures, and produces recoverable/salable by-products.

RPT technologies are designed to operate in the gas phase and may not be applicable for direct treatment of liquid or solid wastes. However, technologies such as air stripping could be used to volatilize contaminants from soil or groundwater prior to treatment. The technology cannot treat contaminants such as metals.

Technology Cost

According to the vendor, bench-scale results indicate that RPT technologies can be cost effective. Based on early experiments treating trichloroethene (TCE), costs were estimated at \$2.64/lb of TCE converted. The vendor states that this amount is much less than the cost of treatment using absorption on activated carbon (estimated at \$40/lb) (D18003A, p. 25).

Other estimates range from \$0.40 to \$1.00/lb of treated compound. The cost per unit volume was estimated by the vendor to be \$0.014 to \$0.124/ft^3 of air treated. The actual costs will depend on the specific composition of the waste stream (D18004B, p. 4).

A cost analysis based on laboratory and prototype studies indicated that treatment costs would be competitive with similar technologies. TCE was used as a representative contaminant for this analysis. It was determined that the treatment of 1000 ft^3 of air containing 10 parts per million (ppm) of TCE would cost $0.13. Treating the same quantity of air containing 1000 ppm of TCE would cost $0.33 (D21009T, p. 123).

Information Sources

D18004B, Energia, Inc., undated vendor literature

D18003A, Energia, Inc., undated vendor information

D21009T, U.S. EPA, 1999

T0249

Energy and Environmental Research Corporation (EER)

Spouted Bed Reactor (SBR)

Abstract
The spouted bed reactor (SBR) was designed to treat organic wastes by pyrolysis and gasification. The gaseous products can then be used in combustion equipment, used for power production in prime movers or, alternatively, chemical products can be recovered. A secondary slagging cyclone removes solids and may be fueled with oxygen to increase temperature for slag glassification. The glassified waste may trap heavy metals and prevent them from leaching.

The technology is applicable to wastes that are contaminated with organic compounds and heavy metals and that have significant heat content, which should range from 3000 to 12,000 Btu per pound. The technology also treats soils contaminated with coal tar residues, petroleum refinery wastes, and municipal solid wastes, chemical waste, munitions, and rocket propellants.

Energy and Environmental Research Corporation (EER) developed the SBR technology but has since abandoned further development of the product (personnel communication: Jerry Cole: EER, January 1997).

Technology Cost
No available information

T0250

Energy and Environmental Research Corporation

Reactor Filter System

Abstract
The reactor filter system (RFS) is designed to control gaseous and entrained particulate matter emissions from the primary thermal treatment of soils, sludges, and sediments. During the thermal treatment of these materials, products of incomplete combustion and volatile toxic metals are often produced and discharged with the effluent gases, requiring further treatment. This technology seeks to control these emissions by reacting them with an aluminosilicate sorbent and filtering out the insoluble, nonleachable products (D10678F, p. 1).

Further development of the RFS technology was discontinued by Energy and Environmental Research Corporation (EER), and the technology is not commercially available.

Technology Cost
There is no available information about the costs associated with this technology.

T0251

Energy Biosystems Corporation

Biocatalytic Desulfurization

Abstract
Energy Biosystems Corporation has developed a biocatalytic pilot plant that removes sulfur from crude oil. The biocatalyst is based on a soil bacterium isolated for its ability to selectively desulfurize fossil fuels. The relevant genes from these bacteria have been isolated and are being manipulated and transferred to alternative microbial hosts to increase expression of the desired properties. This leads to increased efficiency of the process. Currently, this technology is being optimized for eventual commercialization for the petroleum industry.

The basic process involves the following steps:

- Biocatalyst is combined with water and transferred to the bioreactor.
- Biocatalyst slurry and high-sulfur petroleum feedstock are mixed with oxygen in a continuous stirred-tank reactor.
- Desulfurized petroleum is separated from the aqueous/biocatalyst output stream.
- Sulfur by-product is removed from the process in the aqueous phase as sulfate that can be disposed of as sodium sulfate (saltwater) or ammonium sulfate (a fertilizer), depending on local conditions.
- Biocatalyst/water mixture is recycled to the bioreactor after spent biocatalyst is removed.

Currently, the process can only be used for desulfurization of oil in the refining industry.

This technology is included in RIMS without the express approval of the developer. It is included because the technology could have application for remediation in the future.

Technology Cost
No available information.

T0252

Energy Products of Idaho

Fluidized-Bed Combustion

Abstract
Fluidized-bed combustion systems use a heated bed of sandlike material suspended (fluidized) within a rising column of turbulent air to burn many types and classes of waste fuels. The vendor claims that this technique results in improved combustion efficiency of high moisture content fuels and is adaptable to a variety of "waste"-type fuels. The scrubbing action of the bed material on the fuel particle is said to enhance the combustion process by stripping away the carbon dioxide and char layers that normally form around the fuel particle. This allows oxygen to reach the combustible material much more readily and increases the rate and efficiency of the combustion process.

This technology is currently commercially available.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information

T0253

Energy Reclamation, Inc.

Pyrolytic Waste Reclamation (PWR)

Abstract
Energy Reclamation, Inc., has developed the pyrolytic waste reclamation (PWR) system for the treatment of liquid organic wastes. PWR uses a hydrogen-powered plasma torch operated in the absence of oxygen and nitrogen to break down liquid organic wastes, creating mainly hydrogen gas and solid carbon. For hydrocarbon materials containing chlorine, a wet scrubber is used to remove chlorine from the system. The hydrogen gas is used in a feedback mode to operate the plasma torch, and the solid carbon can be sold as a commercially viable product. In late 1998, the president of Energy Reclamation, Inc., confirmed that the company had gone out of business.

The vendor claims that the PWR system is capable of treating all organic liquids, including solvents, polycyclic aromatic compounds (PAHs), polychlorinated biphenyls (PCBs), and volatile organic compounds (VOCs). Vendor states that the PWR system recycles hydrogen produced during treatment to meet energy requirements and that the solid carbon produced by the process allows for revenue generation. Vendor also claims that the process cannot produce carbon dioxide or dioxins during treatment.

Wastes must be in liquid form, with no suspended solids, to be treated by PWR technology. Wastes containing water also require a centrifuge separation step.

Technology Cost
There is no available information regarding the costs associated with this technology.

T0254

EnerTech Environmental, Inc.

SlurryCarb Process

Abstract
EnerTech Environmental has developed the SlurryCarb™ process, which is designed for the ex situ conversion of municipal and other high-organic wastes into a liquid fuel. The vendor claims the technology uses a liquid-phase reaction in the absence of air to increase the energy value and homogeneity of the wastes. The reaction takes place at temperatures ranging from 225 to 350°C, under sufficient pressure to keep the slurry substantially liquid. The vendor has termed the end product of this reaction E-Fuel™. According to the vendor, the SlurryCarb process has been evaluated at a pilot-scale facility and a semicommercial facility has been designed. In Japan, a 20-ton/day facility began operation in March, 1997. The vendor is currently seeking partners and a site for the construction of a demonstration unit in the United States. The vendor hopes to enter the design and construction phase by 1998.

The vendor claims the following advantages of the SlurryCarb system:

- Accepts a variety of wastes with different compositions, and presorting is minimized.
- Wastes are converted into a renewable fuel source at costs competitive with municipal waste combustion facilities.
- Estimated cost of disposal ranges from \$50 to \$55 per received ton of solid municipal waste (includes cost of resource recovery, depreciation, and cost of capital).

No information is available on the limitations of the technology.

Technology Cost
In undated vendor literature, EnerTech claimed that the capital costs for a 500-ton/day SlurryCarb facility in the United States would cost approximately $50,000,000. Gross yearly operating costs were estimated at $9,000,000 to 11,000,000. The required tipping fee was estimated at $40 to $50 per ton. The vendor claims the costs are more in the range of $50 to $55 per ton. For this estimate, it was assumed that the plant would be in operation 330 days per year, 24 hours a day, using a waste feed that was 20% moisture. The vendor noted that as the moisture content feed of the waste increases, the cost of treatment decreases. For the above facility, it was estimated that the economic value of the created fuel (E-Fuel) would be $1.50 per million British thermal units (Btu). The vendor states that it can provide a detailed economic analysis of the SlurryCarb process to interested parties, after a confidentiality agreement has been signed (D16320C, p. 6).

Information Source

D16320C, EnerTech Environmental, undated vendor literature

T0255

EnSafe, Inc.

Bioreactor for Treatment of Perchlorate

Abstract
EnSafe, Inc., has developed an ex situ bioreactor system for the treatment of perchlorate-contaminated soil and groundwater. The technology involves placing contaminated media into specially designed treatment cells or tanks containing a carbon source, nutrients, and a pH buffer. The carbon source creates an anaerobic environment that promotes the breakdown of perchlorate by indigenous microorganisms.

EnSafe's bioreactors have been used in the field to reduce perchlorate concentrations in soils from a maximum concentration of 1,800,000 to 270 μg/kg. Groundwater concentrations have been reduced from 23, 000 μg/liter to below detection limits using the technology. EnSafe's bioreactor systems are commercially available.

Technology Cost
Several treatment technologies were considered for use at a U.S. Department of Defense (DOD) site in Texas that was contaminated with perchlorate. The EnSafe bioreactor was finally chosen over ion exchange treatment methods because the bioreactor was considered more cost effective for treating intermediate to high concentrations of perchlorate (D21213V, p. 26).

Information Source

D21213V, Cowan, 2000

T0256

Ensite, Inc.

SafeSoil Biotreatment System

Abstract
SafeSoil is an ex situ, biostimulation treatment technology that is specifically designed to remediate soil contaminated with organic compounds. The SafeSoil process biologically oxidizes

organic compounds into carbon dioxide, biomass, and water. The technology uses the natural abilities of soil microorganisms to degrade organic compounds to stimulate an enhanced microbial growth rate; organic compound metabolism produces this enhanced biodegradation rate.

The SafeSoil technology combines the best elements of various other forms of bioremediation, such as adding organic nutrients (simple sugars and proteins), and including inorganic nutrients in the additive. The technology uses effective mixing techniques (much like bioreactors), which produces more efficient contaminant mass transfer without generating the high liquid-to-solids ratios observed with bioreactors.

The SafeSoil technology does not require additional soil processing. All required nutrients are supplied during the initial processing step. The unique air entrainment feature of the treatment process provides an initial supply of oxygen, eliminating the need for soil tillage. The entrainment feature also permits passive air diffusion by generating a honeycomb lattice structure, allowing oxygen to passively diffuse, thus maintaining aerobic conditions.

The SafeSoil technology is generally faster than most in situ bioremediation applications and generally provides better process control than in situ applications, resulting in a higher degree of reliability in final treatment.

SafeSoil has been used primarily on soils contaminated with petroleum products, since these contaminants are most susceptible to biological treatment. Full-scale studies indicate that the SafeSoil technology successfully treats soil contaminated with solvents, gasoline, waste oil, jet fuel (JP-4), kerosene, diesel fuel, creosols, and phenols.

Any conditions that inhibit bacterial growth will reduce the effectiveness of the SafeSoil technology. Trophic interactions between many groups of microorganisms cause rate-limiting factors, such as temperature and population ecology-derived factors. The SafeSoil technology is not applicable to soil contaminated solely with metals, radionuclides, or other inorganics but has been used primarily on soils contaminated with petroleum products, which are most susceptible to biological treatment.

Technology Cost

The treatment cost of the SafeSoil process is comparable to incineration but is usually substantially lower (20 to 60%) (D10242R, p. 5). The estimated treatment cost for the SafeSoil process ranges from $19 to $89 (D10127P, p. 40).

Information Sources

D10242R
D10127P

T0257

EnSolve Biosystems, Inc.

EnCell Bioreactor

Abstract

The EnCell™ bioreactor is an ex situ device containing microorganisms designed for the treatment of toxic water pollutants. According to EnSolve, unique features of the EnCell bioreactor include a high biomass support media and a slow-release nutrient delivery system. According to the vendor, applications of this technology include cleanup of agricultural wastes, ship bilges, industrial waste streams, leaking underground storage tank (UST) sites, and laboratory wastes.

This technology is currently commercially available.

All information is from the vendor and has not been independently verified.

Technology Cost

No available information.

T0258

ENSR Consulting and Engineering

Anaerobic Biotransformation with Steam Injection

Abstract

The process of anaerobic biotransformation with steam injection is a technology for the in situ remediation of soils and groundwater contaminated with dense non-aqueous-phase liquids (DNAPLs). Using this approach for remediation, steam is injected into the soil to volatilize and remove DNAPLs, with the simultaneous introduction of nutrients. The resulting subsurface conditions are suitable for biotransformation of the dissolved phase, into compounds that are more easily removed by vapor and groundwater extraction.

This technology is designed for the remediation of soils and groundwater contaminated with halogenated aliphatic compounds such as trichloroethylene (TCE) and trichloroethane (TCA) (D15071A, p. 5). It can accomplish this in a shorter time frame than conventional pump-and-treat methods, at a lower cost per pound of removed contaminants. This patented process was developed by AT&T Bell Laboratories and ENSR Consulting and Engineering and is currently in use and is commercially available.

Technology Cost

The cost of this system is very site specific. It is dependent on many factors, including hydrogeology, geology, and water chemistry. There is currently only one example of the actual costs for the use of this technology. In the treatment performed at a former AT&T plant, solvent was removed at a cost of $132/lb. The total cost of operations at the site was $3.44 million (D14286J, p. 7).

Information Source

D14286J, Smith and Ferguson, undated

T0259

ENSR International Group

Biovault

Abstract

Biovault is a commercially available, nonproprietary, ex situ treatment for soil and sediment contaminated with chlorinated and nonchlorinated volatile organic compounds (CVOCs and VOCs). The basic biovault process is to promote the degradation of the existing soil contaminants in consolidated piles by stimulation of the indigenous (or augmented) microbial population. The process typically includes low-intensity aeration, moisture control, and supplementation with nutrients.

Biovault technology alone is not an effective treatment for creosote- and pentachlorophenol (PCP)-contaminated soils. Inorganic wastes are not typically treatable biologically, and biovault technology may not be practical for contaminants with low rates of degradation or very high volatility, such as vinyl chloride.

Technology Cost

An ENSR International Group biovault at the Port of Los Angeles (POLA) treated 3500 yd^3 (2676 m^3) of contaminated soil in two cells for \$35/yd^3 (\$46/m^3) plus construction costs. An uncovered vault using simplified construction methods at a Marine Corps Base treated 10,000 yd^3 (7646 m^3) of soil at an estimated cost of \$35/yd^3 (\$46/m^3). Dates of these remediations were not given (D124549, p. 9-6).

The ENSR International Group/Larson project (see Case Study 1) cost \$140,600 for construction, oversight, monitoring, permitting, reporting, and demobilization. The laboratory analytical costs for the demonstration under the U.S. Environmental Protection Agency's Superfund Innovative Technology Evaluation Program were approximately \$75,000, not including sample collection, oversight, data validation, and reporting. The site preparation and restoration costs are estimated by NYSDEC to have been \$55,000 per vendor. The soil volume was 200 yd^3 (153 m^3), which produces a treatment cost of \$1353/yd^3 (\$1769/m^3). The following factors should be taken into consideration concerning the costs associated with this demonstration:

- Project was bid at cost with no profit margin, so the labor costs per hour are low.
- Vault size is very small, so the unit cost of construction and operation is very high.
- Level of sampling and analysis was far beyond that normally used for site monitoring and closure (D124549, p. 9-1).

Information Source

D124549, ENSR, April 1996

T0260

ENSR International Group

Soil Cleaning Process

Abstract

ENSR International Group soil cleaning process is an ex situ treatment for soils contaminated with petroleum hydrocarbons. The process uses a combination of soil washing and solvent extraction. Soil washing removes heavy metals and hydrocarbons from coarse soil particles, resulting in a reduced volume of material to be treated by solvent extraction. Solvent extraction uses a chemical additive that enhances the extraction of hydrocarbons from soil particles in an aqueous slurry.

The aqueous soil washing system is used to classify the particles into a coarse and fine fraction. The coarse fraction is cleaned by the use of heat, chemicals, and mechanical energy. This material can be returned to the site as clean backfill. The fine fraction is thickened and sent to the solvent extraction unit.

Aqueous soil washing cannot handle viscous materials such as tars, and it cannot separate contaminants if they have the same size and specific gravity as the soil particles.

Solvent extraction will not remove metals from fine soil particles. It will only extract contaminants that are soluble in the solvent, including the most commonly occurring hydrocarbons.

Soils containing more than 10% water can cause the soil/solvent slurry to form emulsions and either agglomerate or coat the walls of the process vessels. As a result, the solvents do not adequately contact the soil for effective contaminant extraction. The vendor claims to have solved this problem by adding a small amount of a proprietary reagent to the soil in the initial process step.

The technology is not commercially available, and the company no longer deals with this particular technology.

Technology Cost

The cost of remediating 15,300 m^3 of soil using the ENSR International Group soil cleaning process was estimated to be between \$164/m^3 and \$327/m^3 in 1989. This estimate was based on operation of a mobile system with net daily throughput rates of 96 to 191 m^3/day, and an on-stream factor of 85%. These estimates included capital and operating expenses, waste disposal, mobilization, and demobilization (D14528I, p. 5.4).

According to the vendor, costs are highly dependent on the amount of material to be treated. Vendor-estimated costs in 1995 ranged from \$125 to \$350 per ton of soil treated (D10120I, p. 2).

Information Sources

D14528I, Anderson, 1995
D10120I, VISITT, July 1995

T0261

Enviro Products, Inc.

PetroTrap

Abstract

The PetroTrap™, a passive skimming system, is a long and narrow cylindrical device that uses an active buoy/filter system to remove free-floating hydrocarbon product from a well and store it in a collection cannister. The unit uses no electricity and can be installed quickly. According to the vendor, the PetroTrap is applicable for the recovery of most refined fuels.

The PetroTrap was developed by Enviro Products, Inc., who later introduced the PetroTrap-E for sites with minimal fluctuations in the groundwater level. Both products are currently in use and are commercially available.

Technology Cost

The PetroTrap is available from the vendor at a cost of \$885.00 per unit. The standard system includes a PetroTrap skimmer assembly (2- or 4-inch-diameter model), a 25-ft suspension hose, and a locking well cap (D17074L, p. 4).

PetroTrap-E units are available at a cost of \$585.00 and \$635.00 for the 2- and 4-inch-diameter units, respectively. Additional canisters are available that double a unit's capacity (PetroTrap or PetroTrap-E), at a cost of \$115.00 per cannister (D17074L, pp. 1, 2).

Information Source

D17074L, Enviro Products, Inc., 1995

T0262

Envirocare of Utah, Inc.

Polyethylene Encapsulation

Abstract

Envirocare of Utah, Inc. (Envirocare) has commercialized the polyethylene encapsulation process developed by Brookhaven National Laboratory (BNL) as an ex situ stabilization technology for hazardous and mixed wastes (wastes with both hazardous and radioactive components).

Polyethylene is an organic polymer with an amorphous crystalline structure, formed by the polymerization of ethylene gas. A low-density polyethylene with a processing temperature of 130 to 150°C has been evaluated in bench-scale and full-scale tests as a final waste form for evaporator concentrates, sludges, blowdown solutions, incinerator ash, and ion exchange resins.

BNL claims that polyethylene encapsulation allows for greater waste loading and has a better waste form performance than conventional cement solidification, allowing for 70% fewer drums to be processed and shipped for disposal of some government waste streams. The technology is commercially available.

Polyethylene encapsulation does not destroy wastes; it is a stabilization technology. The process works best with dry waste streams with less than 1% moisture. Polyethylene has a flammability rating of 1 (slight) according to the National Fire Protection Association. Flash ignition temperature of polyethylene is 409°C, and self-ignition temperature is 430°C. When cooled below flash ignition temperatures, polyethylene is self-extinguishing. Polyethylene could become brittle when exposed to ultraviolet radiation, or conditions that can lead to environmental stress cracking.

Technology Cost

In 1991, Kalb et al. prepared a cost estimation comparing polyethylene encapsulation of nitrate salts with two common types of cement encapsulation, Rocky Flats Plant (RFP) Cement and West Valley (WV) Cement. Maximum salt loading was estimated at 70 weight percent (wt%) polyethylene, 13 wt% RFP Cement, and 20 wt% West Valley Cement. Processing 1 million kilograms of waste would require 4343 drums using polyethylene encapsulation, versus 22,303 drums using RFP Cement, and 15,611 drums using WV Cement (D12141V, pp. 63–68). Cost comparisons are given in Table 1.

During a 1996 full-scale demonstration for the U.S. Department of Energy (DOE), Envirocare macroencapsulated approximately 500,000 lb of radioactive elemental lead. Costs were shared between Envirocare and DOE under the terms of the cooperative agreement. Envirocare paid for equipment, supplies, facility construction, facility modification, permitting, and personnel

TABLE 1 Economic Analysis for Nitrate Salt Encapsulation at Rocky Flats Plant[a]

	Polyethylene	Rocky Flats Plant Cement	West Valley Cement
Labor costs[b]	$444,612	$444,612	$444,612
Repair costs[b]	37,841	37,841	37,841
Miscellaneous costs[b]	45,454	45,454	45,454
Cement costs[c]	0	1,436,743	909,856
Polyethylene costs[d]	425,057	0	0
Shipping costs[e]	186,077	978,560	667,998
Disposal costs[e]	63,345	333,127	227,404
Drum costs[e]	151,501	778,055	544,600
Waste pretreatment costs[b]	527,907	527,907	527,907
Total costs	$1,881,795	$4,582,299	$3,405,673
Unit cost $/kg salt	$1.88	$4.58	$3.41

Source: From D12141V.
[a] Stabilization of one million kilograms/year nitrate salts.
[b] Assumed equal for all methods.
[c] Cement cost 22 cents/kg.
[d] Polyethylene cost 99 cents/kg.
[e] Based on a constant cost/drum.

training. In addition, Envirocare provided facilities for the treatment and disposal of wastes. DOE paid for the treatment and disposal of the encapsulated waste (D18512Q, p. 157).

DOE's cost for disposal during the 1996 demonstration was about $1 million for 500,000 lb, or approximately $1.92/lb (D18512Q, p. 157). This amount, which included substantial treatability studies and costs for scaleup experiments, represented about half the cost of storing the waste (D18512Q, p. 157; D20697N, p. 3). An estimate of current costs for polymer macroencapsulation are $90 to $100/ft^3. Operating costs at DOE sites average about $800 per 55-gal drum (D18512Q, p. 157).

Appropriate polymer extruders for this application can cost between $50,000 and $160,000 (D18512Q, p. 167). Other sources price extrusion processing systems at $250,000 (D11180Y, p. 1; D112572, p. 5). Integrated systems, which include pretreatment components, can be as high as $1,000,000 (D11180Y, p. 1; D112572, p. 5).

Actual costs incurred by Envirocare are considered proprietary information and are not disclosed. Costs for ancillary equipment, such as feed hoppers and transfer systems, total approximately $10,000. Virgin low-density polyethylene costs approximately $0.61/lb, or less depending on purchase volume. Recycled material costs about one-third as much, but supplies tend to be unreliable (D18512Q, pp. 167, 168).

Since polyethylene encapsulation is an approved treatment technology, neither waste form qualification testing nor off-gas monitoring are required. This factor results in significant cost savings when compared to destruction and separation technologies (D18512Q, p. 168).

Information Sources

D12141V, Kalb et al., 1991
D18512Q, Federal Remediation Technologies Roundtable, 1998
D11180Y, GNET, 1995
D112572, WEBTECH, 1994
D20697N, Bonzon, 1996

T0263

Envirogen

Adhesion-Deficient Bacteria

Abstract

Adhesion-deficient bacteria are used for the in situ treatment of chlorinated organics commonly found in groundwater contaminants. Unlike many wild-type bacterial strains, adhesion-deficient bacteria do not readily sorb on to sediment surfaces. This enhances the ability of degradative microorganisms to be transported through aquifer solids to the zone of contamination and accelerates the rate of bioremediation. The technology is proposed for use in treating a number of chlorinated organic contaminants such as trichloroethylene (TCE). The technology is not commercially available.

Envirogen has been conducting research on adhesion-deficient bacteria under a subcontract with the U.S. Department of Energy (DOE). This research is part of a strategy to use adhesion-deficient bacteria in conjunction with surfactants and biosurfactants to accelerate rates of in situ biological remediation. As of June 1995, several candidate sites were being evaluated for the potential application of the technology. Aquifer material from these sites will be used for examination of degradation of sorbed TCE.

Technology Cost

No available information.

T0264

Envirogen

TCE-Degrading Bacteria

Abstract
TCE-degrading bacteria is a patented technology for the treatment of soil, groundwater and wastewater contaminated with trichloroethylene (TCE). The particular strain of bacteria used in this technology does not require the addition of a toxic co-substrate to activate the bacterial destruction of TCE. The technology can be used to remediate virtually any media type contaminated with one or more volatile organic compounds (VOCs), including TCE, and can be used for in situ or ex situ bioremediation.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0265

Envirogen, Inc.

Electrokinetic Transport

Abstract
Electrokinetic transport is a patented, in situ, commercially available technology for the bioremediation of organic contaminants in aquifer soils and groundwater. The technology involves the application of a direct electrical current across the area to be treated to facilitate the movement of biodegrading bacteria to the site of contamination.

Contaminants absorbed to aquifer soils can leach into the aquifer even after the groundwater has been treated. Contaminants may also be trapped in areas where the flow of groundwater is restricted. In addition, traditional approaches to in situ bioremediation can be limited by bacterial migration, which can be dependent on hydrogeological gradients or blocked by physical features or structures within the aquifer. Electrokinetic remediation disperses microorganisms capable of biodegrading the target contaminants uniformly throughout the affected area.

Electrokinetics has been used to mobilize metals and dissolved contaminants to in situ treatment or recovery zones. Electrokinetic transport uses these mechanisms to move bacteria through the subsurface to the contaminated media. The technology can be used to treat organic contaminants that adsorb to aquifer soils including halogenated hydrocarbons and non-aqueous-phase liquids (NAPLs).

This technology is not suitable for very dense, low-permeability soils and sediments. However, electrokinetic transport could be used to remediate contaminated clay formations within a more permeable aquifer.

A system of preventing the formation of acid and base fronts at the electrodes may be required, since the formation of these fronts could prevent the bacteria from moving by neutralizing the charge on their membrane or killing them. pH must also be controlled. Extremes in pH could kill the degradative bacteria, and a low pH could result in a positive net charge on the cell surface of bacteria, causing them to be propelled toward the cathode rather than the anode.

Technology Cost
No information available.

T0266

Envirogen, Inc.

Solid Organic Phase Extraction (SoPE)

Abstract

Envirogen's solid organic phase extraction (SoPE) is a commercially available ex situ technology for treating soils and sediments contaminated with hydrophobic organic compounds such as polychlorinated biphenyls (PCBs), polycyclic hydrocarbons (PAHs), creosote, coal tar, selected pesticides, and dioxins. SoPE involves addition of an organic solvent (such as acetone) to the contaminated waste. Water and a solid organic (such as polystyrene beads) are then added. The solid organic adsorbs the contaminants from the solvent, and removes them from the waste. Polymeric foams or rubber such as polyurethane, polypropylene, polyethylene, polystyrene, natural rubber, and synthetic rubber provide suitable solid organic-phase materials. The vendor claims that the technology can reduce the initial volume of contaminated material by up to 99% so that treated soils can be returned to the site as backfill. The technology is run in semicontinuous batch operation.

The vendor claims the following advantages for the technology:

- Reduction in the total cost.
- Reduction in the quantity of solvent used.
- Low-energy requirements.
- Removes targeted compounds with a single pass through the system.
- Treated material can be returned to the excavation as cleaned soil.

The SoPE process is most efficient on materials of high sand content and low moisture content. All information has been provided by the vendor and has not been independently verified.

Technology Cost

Envirogen ran a series of field pilot tests. From these results Envirogen estimates that a complete soil treatment using the SoPE technology should cost in the range of $90 to $140 per ton, excluding the polystyrene disposal (D15804N, p. 58).

Information Source

D15804N, Envirogen, 1996

T0267

Envirogen, Inc.

Spartech

Abstract

Spartech™ is a mobile system designed for the removal of volatile contaminants from aquifers. It is a patented air sparging system that works by bubbling air through an aquifer and is essentially an in situ method of air stripping. The volatilized contaminants may be recovered by using a soil vapor extraction (SVE) system or similar device.

This technology has been applied by itself and in combination with SVE systems, following SVE, as a capillary fringe treatment, and as an underground containment fence. Spartech has been used to remediate aquifers contaminated with halogenated volatile organic compounds (halogenated VOCs), aromatics, ketones, and gasoline- and diesel-range organics.

This technology has been used in the field at numerous sites and is currently commercially available from Envirogen, Inc.

Technology Cost
There is no available information regarding the costs associated with this technology.

T0268

Envirogen, Inc.

Vaportech Enhanced Volatilization

Abstract
Vaportech™ enhanced volatilization is designed to remove volatile contaminants from vadose zone soils in situ. The technology operates by injecting clean air around the perimeter of the contaminated area and withdrawing contaminated air from the middle.

The Vaportech technology has been used in the past to treat soils contaminated with chlorinated solvents such as perchloroethylene (PERC) and trichloroethylene (TCE); benzene, toluene, ethylbenzene, xylenes (BTEX); aromatics, ketones, gasoline-range and diesel-range organics, phenols, and other cyclic and noncyclic carbon compounds including ketones, naphtha, mineral spirits, and lacquer diluter.

Heavier soils with lower pneumatic conductivities require a significantly more intensive effort to induce airflow and may prove prohibitive to treat with this or similar technologies.

Soil vapor extraction is a commercially proven technology, and according to the vendor, the Vaportech enhanced volatilization method has been used in many full-scale remediations. The developer has performed field studies using hot air injection to further enhance the performance of this technology. The Vaportech technology is commercially available from Envirogen, Inc., formally MWR, Inc.

Technology Cost
There is no available information regarding the costs associated with the use of the Vaportech enhanced volatilization technology.

T0269

Enviro-Klean Technologies Inc. (EKTI)

KLEAN-MACHINE

Abstract
Enviro-Klean Technologies Inc's (EKTI) KLEAN-MACHINE is a patented ex situ, low-temperature thermal desorption technology used to treat petroleum-contaminated soils. The KLEAN-MACHINE treats soil contaminated with hydrocarbons, volatile organic compounds (VOCs), and petroleum hydrocarbons (with a carbon chain length of 45 carbons or less). The technology also cleans baghouse fines.

The technology can potentially treat the following contaminants: halogenated volatiles and semivolatiles, nonhalogenated volatiles and semivolatiles (also listed as actual), organic pesticides/herbicides, polynuclear aromatic compounds (PNAs), solvents, and benzene-toluene-ethylbenzene-xylene (BTEX).

The technology is applicable at gasoline/service station sites or in petroleum refining and reuse. The technology can be used for the following treatment applications: agriculture, coal gasification, dry cleaning, herbicide manufacturing or use, industrial landfills, inorganic or organic pigments, machine shops, municipal landfills, paint or ink formulation, pesticide manufacturing or use, pulp and paper industry, wood preserving, and organic chemical manufacturing.

The KLEAN-MACHINE cannot treat the following:

- Materials more than 2 inches in size
- Clays with a moisture content greater than 5%, and other soils with a moisture content of more than 20%
- Inorganic wastes, polychlorinated biphenyls (PCBs), dioxins, pesticides, cyanides, or corrosives

Technology Cost

The estimated cost range for using the KLEAN-MACHINE is \$55.00 to \$100.00 per ton of waste treated (D10121J, p. 42).

The costs for using the KLEAN-MACHINE at the following sites were as follows (D10121J, pp. 8–10, 13–15, 18–20, 23–25, 28–30, 33–35):

- Texaco Gas Station, Auburn, WA (gas station)—\$78/yd^3; total project cost: \$7800 for 100 yd^3 of soil
- Public Utility, Gig Harbor, WA (gasoline station)—\$38/yd^3; total project cost: \$13,300 for 350 yd^3 of soil
- Budget Rent-A-Car, Seattle, WA (gasoline service station)—\$43/yd^3; total project cost: \$24,000 for 560 yd^3 of soil
- Washington National Guard Armory, Snohtomish, WA (gasoline service station)—\$52/yd^3; total project cost: \$6500 for 125 yd^3 of soil
- Medical Park, Covington, WA (gasoline service station)—\$38/yd^3; total project cost: \$22,800 for 600 yd^3 of soil
- Bjornchy Auto Rebuild, Seattle, WA (gasoline service station; machine shops)—\$82/yd^3; total project cost: \$16,400 for 200 yd^3 of soil

Among the factors that affect the unit prices are (D10121J, p. 42):

- Moisture content of the soil
- Boiling point (carbon chain length) of contaminant (D126067, p. 9)
- Soil characteristics
- Target contaminant concentration
- Waste handling/preprocessing
- Labor/utility/fuel rates

Information Sources

D10121J, VISITT 4.0

D126067, EnviroTrade (U.S. Department of Energy)

T0270

EnviroLogic Engineering

Microbial Cleaners

Abstract
Microbial cleaners (MCs) are a mixture of specially selected microorganisms and biocatalysts designed for the bioremediation of organic contaminants in soil or water. According to the vendor, MCs have been used in multiple full-scale applications and are commercially available from EnviroLogic Engineering.

All information was provided by the vendor and has not been independently verified.

The microbes will not survive an excessive amount of bleach or any bacteride, pH above 11 or below 4, or temperature higher than 120°F. This technology cannot handle metals and is only applicable to biodegradable hydrocarbon contaminants.

Technology Costs
A 1997 price list gives the following retail prices:

- $49.95/gal—1-gal pack
- $39.95/gal—4 gal (one case)
- $34.95/gal—40 gal and more
- $31.95/gal—for large quantities, long-term arrangements, or 55-gal drums

TABLE 1 Vendor Supplied MC–Soil Cost Analysis

		Working Solution Actual Cost		
Application	Water Dilution Rate	@$49.95/gal	@$39.95/gal	@$34.95/gal
General application cleaner	1:64	$0.77/gal	$0.62/gal	$0.54/gal
Oily floors cleaning	1:32	$1.51/gal	$1.21/gal	$1.06/gal
Parts cleaners	1:4	$9.99/gal	$7.99/gal	$6.99/gal
Soil remediation and outdoors spill cleanup	1:4	$9.99/gal	$7.99/gal	$6.99/gal
	Surface contamination:			
	1 gal/20 yd^2 for sand	$0.49/yd^2$	$0.39/yd^2$	$0.34/yd^2$
	1 gal/4.5 yd^2 for clay	$2.22/yd^2$	$1.77/yd^2$	$1.55/yd^2$
	Excavated soil:			
	1 gal/ton	$9.99/ton	$7.99/ton	$6.99/ton
Petroleum, solvent, and oil spill (indoors)	1:4	$9.99/gal	$7.99/gal	$6.99/gal
Reconditioning of used petroleum spill sock sorbents	1:16	$2.94/gal	$2.35/gal	$2.06/gal
Ponds, lagoons, and oil pits	Formula: $ft^2/81$ = gal of formula 1	N/A	N/A	N/A

Table 1 gives a more detailed cost analysis of MC–soil use.

Information Source

D16670V, vendor literature

T0271

EnviroMetal Technologies, Inc.

EnviroMetal Process

Abstract

The EnviroMetal Process™ is a patented process of metal-enhanced reductive dehalogenation using zero-valent iron. The technology can treat some metals, volatile organic compounds (VOCs), and other chlorinated hydrocarbons in groundwater. The EnviroMetal Process can be used in an aboveground reactor or as an in situ treatment wall installed across the flow path of a contaminant plume. Granular zero-valent iron acts as the treatment media in the oxidation–reduction reaction. When the reactive iron comes into contact with contaminated water, the iron is oxidized, and the VOCs or metals are reduced to benign products such as simple organic compounds and halogen salts. The EnviroMetal Process has been implemented in a number of pilot- and full-scale site remediations, including the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration program. The technology is commercially available.

The vendor states the EnviroMetal Process has the following advantages:

- It requires low energy input, little water, and limited operation and maintenance costs.
- The reactant is inexpensive and a common industrial by-product.
- If used in situ, the land can be returned to useful purposes.
- Little potential exists for cross-media contamination.
- It has low or no treatment and disposal costs.
- It has favorable public perception.
- Products are benign.

The technology has several potential limitations. When the system is used to remediate groundwater with a high mineral content, the granular iron may need to be flushed or replaced every few years. If the iron is not replaced or regenerated, precipitates formed during treatment could reduce flow rates and block the available surface area of the reactive iron. Suspended solids can also block reactive walls. The temperature of the groundwater may affect the rate of the reaction for some contaminants. For ex situ systems, potential problems may include algal growth and exposure to freezing temperatures.

Technology Cost

The vendor states that savings associated with the EnviroMetal Process are due to the low operation and maintenance costs for treatment walls. Because contaminants are destroyed rather than removed, process monitoring costs are negligible, and little or no waste products require disposal or regeneration on a regular basis. The vendor also states that since the technology is a passive treatment, there is no need for manual labor to operate, monitor, and maintain the system (D14522C, pp. 19, 20).

TABLE 1 EnviroMetal Process Permeable Treatment Wall Costs

Installation		Costs		
Scale/Year of Installation	Depth in Feet	Construction	Media (Iron)	Total
Full scale/1994	20	$550,000	$170,000	$720,000
Pilot scale/1995	17.5	$105,000	$32,500	$137,500
Full scale/1995	40	—	—	$375,000
Large pilot scale/1996	30	$350,000	$50,000	$400,000
Full-scale estimate	40	$1,200,000	$900,000	$2,100,000
Full-scale estimate	20	$300,000	$135,000	$435,000
Full-scale estimate	15	$130,000	$52,500	$182,500

Source: Adapted from D12777P, D169362, and D21296E.

The reactive iron required for the process costs approximately $375 to $450 per ton (D12778Q, p. 88; D213354, p. 5). Because the EnviroMetal technology is a patented process, a licensing fee (approximately 15% of capital costs) may also be required (D20317Y, p. 29). Capital cost information for several in situ EnviroMetal Process installations is summarized in Table 1.

In 1996, the vendor stated that the average price of an in situ system, based on 60 cost estimates, was $450,000 for construction costs, $225,000 for media costs, and $775,000 for the average total cost. The vendor stated that the following factors affected treatment costs:

- Influent contaminant concentration
- Groundwater velocity
- Contaminant degradation rates
- Depth, width, and saturation thickness of the plume
- Reactive media used
- “Funnel” material used (if needed)
- Other site characteristics (D169362)

An in situ system operating at a former semiconductor facility in California has a net present value (NPV) over a 30-year lifetime of approximately $4.4 million. This represents a $3.4 million savings over the estimated 30-year NPV for the pump-and-treat system that was formerly operating at the site. Both estimates of NPV include capital as well as operations and maintenance costs (D12777P).

The EPA estimated that costs for a full-scale EnviroMetal continuous-wall system would cost approximately $18 per 1000 gal of groundwater treated. An EnviroMetal funnel-and-gate system would cost approximately $20 per 1000 gal of groundwater treated. These estimates are based on the treatment of groundwater contaminated with volatile organic carbons (VOCs) and a 20-year operating period. The EPA also notes that in situ costs can be highly site specific (D20090Y, p. 3).

Process costs for an ex situ system used in the EPA’s SITE demonstration in New Jersey were approximately $91 per 1000 gal of groundwater treated (D206268, p. 1). In 1996, the vendor estimated that the installation of an aboveground system similar to that used in the New Jersey SITE demonstration would cost about $48,000. This estimate includes all equipment and construction costs. Costs for hydrogeologic characterization, treatability studies, permitting, and extraction of the contaminated groundwater were not included because these additional costs will vary widely based on site-specific conditions. The vendor estimates that the minimum annual operations and maintenance costs would be about $10,000. This figure includes electrical consumption, expendable supplies (such as sediment filters), and maintenance labor costs but does not include costs for effluent sampling and analysis (D14255C).

Information Sources

D12778Q, Focht et al., Remediation/Summer 1996
D12777P, Vogan et al., undated
D14255C, U.S. EPA, 1996
D14522C, Clark et al., 1996
D169362, Gillham, 1997
D20090Y, U.S. EPA, 1998
D20317Y, Vidic and Pohland, 1996
D206268, U.S. EPA, undated
D21296E, U.S. EPA, 1999
D213354, Ott, 2000

T0272

Environment Canada

Microwave-Assisted Process (MAP)

Abstract

The Microwave-Assisted Process (MAP™) technology uses microwaves, and solvents that are relatively transparent to microwaves, to extract chemicals from various matrices based on the temperature differential between the solvent and the target compound. According to the developers, the technology is applicable to soils and wastes containing polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), total petroleum hydrocarbons (TPH), and other organic compounds.

When compared with conventional extraction and sample preparation methods, the developer claims that the MAP™ technology reduces production time, energy, solvent consumption, and waste production, while increasing extraction yields and product purity.

The MAP technology was originally developed by Environment Canada for the extraction of aromas, flavors, and coloring from plant material such as paprika. Environment Canada owns the intellectual rights and has had patents either issued or pending for this technology in five continents. Several licenses have been granted for various applications of the MAP in North America and Europe.

A pilot plant has been constructed for evaluation of large-scale applications of the MAP technology, and it is at the pilot stage for extraction of organic contaminants from soil. At the industrial scale, equipment has been designed for contaminant removal from soil and rendering waste streams acceptable for discharge. Advances have also been made in the agrifood, pharmaceutical, process engineering, and engineering applications of the technology.

Technology Cost

There is no available information regarding the costs associated with this technology.

T0273

Environmental BioTechnologies, Inc.

Fungal Composting

Abstract
Environmental BioTechnologies (EBT) is developing fungal composting bioremediation technology for remediation of polycyclic aromatic hydrocarbons (PAHs). Bench-scale studies have been conducted and a field demonstration of the technology has been completed in South Carolina; however, at the time of this writing, sample analysis and data evaluation were still under way. The technology is still in developmental stages.

The fungal soil treatment process begins by growing the fungal culture on cellulosic material in larger and larger batches until sufficient inoculum material is available (5 to 10% of soil weight) for mixing into the PAH-contaminated soil. The contaminated soil is then moistened and stored under warm and aerated conditions that support fungal growth and PAH degradation. Periodically, the soil is mixed to ensure good aeration and effective contacting of the soil by the fungal culture.

More information is needed on factors such as optimal cultures for specific applications, aeration, mixing requirements, timing of microbial and nutrient augmentation, soil type, and bioavailability of hazardous compounds. These parameters will help develop fungal composting as a reliable method for degrading PAHs.

Technology Cost
According to the vendor, fungal soil treatment of polyaromatic hydrocarbon (PAH) contaminated soil is projected to cost $66 to $80 per ton for treatment on-site. These estimates are based on PAH contamination at manufactured gas plant sites (D15145B, p. 7).

Information Source

D15145B, vendor literature

T0274

Environmental Dynamics

Low-Temperature Plasma

Abstract
The Environmental Dynamics low-temperature plasma (LTP) process is an ex situ technology that treats soils contaminated with volatile organic compounds (VOCs). According to the vendor, the technology has the following advantages:

- Processing can be tailored specifically to the type of organic contaminant.
- The entire process is completed on-site.
- The process does not produce hazardous by-products during processing.
- The inorganic portion of the soil is relatively unaffected, allowing for efficient regeneration of organic soil properties.
- The technology processes solid wastes in a single-pass batch mode.

According to the vendor, this technology was developed by the Energy and Environmental Research Center (EERC) at the University of North Dakota in Grand Forks, North Dakota, in cooperation with the U.S. Environmental Protection Agency (EPA).

This technology is not currently commercially available.

All information is from the vendor and has not been independently verified.

Technology Cost

No available information.

T0275

Environmental Fuel Systems, Inc.

Reclaim

Abstract

Reclaim® is a passive, in situ technology that uses a hydrophobic porous polymer to attract, adsorb, and concentrate petroleum hydrocarbons and volatile organic compounds (VOCs) from soils and/or groundwater. Reclaim is considered a passive treatment technology because it requires no mechanical equipment; remediation consists of placing polymer-filled canisters in recovery wells and allowing the containers to attract and adsorb organic contaminants. Reclaim canisters are then recycled and contaminants recovered for analysis and/or disposal. This polymer extracts contaminants whether they are in liquid phase, vapor phase or dissolved phase in water.

Reclaim is commercially available and suitable for the recovery of VOCs, vinyl chloride, trichloroethylene, carbon tetrachloride, dense non-aqueous-phase liquid (DNAPL) compounds, and, in particular, petroleum hydrocarbons. The vendor states this technology has been used in a wide variety of industrial applications, such as the remediation of groundwater at service stations, dry cleaners, herbicide production facilities, and municipal and industrial landfills, among others.

According to the vendor, Reclaim costs less than more traditional remediation technologies and is the only adsorptive process effective for the treatment of VOCs.

Reclaim cannot remove metals or other ionic compounds from groundwater nor catalyze chemical reactions. Also, the success of Reclaim is in relative proportion to the permeability of the geologic components comprising the contaminated site, the hydraulic gradient, and the concentrations and vapor pressures of the contaminants. As permeability, contaminant concentrations, vapor pressure, and hydraulic gradients decrease, so does the rate of recovery. In addition, Reclaim requires vendor-supplied, on-site service and support on a periodic basis.

Technology Cost

According to the vendor, Reclaim costs will vary according to site-specific factors. Contaminant concentrations and soil characteristics will have the greatest impact on cost (D140181; D10111H).

At a closed Texas convenience store/gas station, benzene, toluene, ethylbenzene, and xylene (BTEX) and total petroleum hydrocarbons (TPH) were found in the soil and groundwater throughout the western half of the site. According to the vendor, at $0.62/gal of water treated, total Reclaim costs came to approximately $14,000 (Reclaim treated an average of 21,870 gal per month at this site). Because Reclaim requires servicing by the vendor, a twice-monthly servicing cost must be factored into the overall cost. The servicing cost estimate for this site came to $1350.00 per month (D13884V).

Information Sources

D13884V, Environmental Fuel Systems, date unknown
D140181, Environmental Fuel Systems, date unknown
D10111H, VISITT, 1995

T0276

Environmental Recycling, L.L.C.

Asphalt-Stabilized Base/Engineered Backfill

Abstract
Environmental Recycling, L.L.C., is a Louisiana-based firm that is commercializing a cold-emulsification technology for converting soils contaminated with hydrocarbons and metals into engineered fill and/or asphalt-stabilized base. The technology has been used successfully to convert a wide array of contaminated soils into useful products in Texas, Louisiana, and Georgia. The process combines the contaminated soil with cold asphalt emulsion and, depending on the anticipated end use, with concrete rubble/aggregate. This technology has been applied at sites with hydrocarbon and lead-contaminated soil at rates in excess of 5000 tons per month. The vendor claims that this recycling and reuse process has been proven effective in clay-rich soils that have been especially difficult to remediate by other methods.

This technology differs from other fixation/stabilization technologies in that the mixing process utilizes a combination of contaminated soil with concrete-rubble aggregate, water-based asphalt emulsions, and various other stabilizing agents to produce useful construction materials including roadbed, paving materials, and clean fill.

Since 1992, Environmental Recycling, L.L.C., has applied the asphalt-stabilized base/engineered backfill (ASB/EB) process to soils with high clay content such as are found in the Gulf Coast area. The technology has been effectively used for reuse and recycling at several contaminated sites in Louisiana, Texas, Oklahoma, Wyoming, and Arkansas. It is currently being used at an oil refinery site in Baton Rouge, Louisiana, where hydrocarbon-contaminated soils are being converted to reusable materials.

The process is best suited to treat soil contaminated with hydrocarbons and metals but has also been used to treat dioxin-contaminated soil. This treatment process can also be adjusted to account for soils with excessive moisture.

All information was provided by the vendor and has not been independently verified.

Disposition Option	Cost/Unit[a]	Recoverable Value/Unit	Net Cost/Unit	Average Net Cost/ Unit
Asphalt–stabilized base/engineered backfill	\$30–\$45/ton	\$3–\$12/ton	\$18–\$42/ton	\$30.00
Disposal	\$35–\$55/yard	\$0/yard	\$35–\$55/yard	\$45.00
Bioremediation	\$25–\$45/yard	\$0–\$3/yard	\$22–\$45/yard	\$33.00
Thermal	\$30–\$55/yard	\$0–\$3/yard	\$27–\$55/yard	\$41.00
Soil washing	\$25–\$40/yard	\$(8)–\$3/yard	\$22–\$48/yard	\$35.00

[a] For purposes of this evaluation (based on actual field experience) a ton and a loose yard are considered to be approximately equal.

Technology Cost

The average net cost for this technology is $30 to $45 per ton of soil treated. As shown in the following table, the net cost per unit volume is reduced by subtracting the recovered value of the reusable product. The following table provides a comparison between asphalt-stabilized base/engineered backfill and other remediation options and disposal (D16903T, p. 4).

An independent financial analysis was recently performed of the soil-to-asphalt beneficial reuse program at a clients refinery in Baton Rouge, Louisiana. The analysis was submitted to the Louisiana Department of Environmental Quality as part of a beneficial reuse permit. The analysis determined that this technology creates materials that replace raw materials worth between $9 and $15 per ton. The waste resource conversion saves costs in the following ways: (1) avoiding the purchase of raw materials for construction, (2) avoiding shipping costs of those raw materials, and (3) avoiding the shipping and disposal costs required for off-site disposal. The net saving to one client was between 41 and 51%, avoiding $1.2 and $1.5 million per year using Environmental Recycling's technology instead of an alternative treatment technique (D11597J, p. 3).

Information Sources

D16903T, vendor literature

D11597J, Reith and King, 1997

T0277

Environmental Remediation Consultants, Inc.

BIO-INTEGRATION

Abstract

Environmental Remediation Consultants, Inc. (ERC) offers the BIO-INTEGRATION™ method for in situ and ex situ destruction of organic compounds in soil, sediment, sludge, groundwater, surface water, and wastewater. The BIO-INTEGRATION approach combines biotic and abiotic treatment methods to remediate subsurface contamination. On-site bioreactors are used to grow substrate- and contaminant-specific microbes. The microbes are combined with abiotic amendments and injected into the subsurface.

Amendments may include surfactants, electron acceptors, lubricity enhancers, or chemical stabilization agents. Support mechanisms, such as pumping or fracturing technologies, may also be used.

BIO-INTEGRATION has been field tested and is commercially available through ERC. The vendor stated that BIO-INTEGRATION had allowed for the closure of over 30 impacted sites as of 1998. The vendor has supplied references for several underground storage tank closures and bioremediation projects.

The vendor lists the following advantages of BIO-INTEGRATION technology:

- Applicable to a wide variety of sites and organic contaminants.
- Quickly remediates contaminants, allowing for rapid site closure.
- No volatile compounds are generated, so there are no emission concerns.
- Operates under buildings, railroad tracks, and parking lots.

The technology is limited by the selection of the proper microorganisms. Typically, process bacteria work best at temperatures above 40°F, at a pH range between 4 and 9, and a moisture holding capacity of the soil above 20%.

Technology Cost

The vendor states that BIO-INTEGRATION is not a "one-size-fits-all" protocol (site-specific treatability studies are required to establish the necessary treatment). Thus, treatment cost estimates are highly variable, ranging from $20 to $75 per ton of contaminated soil treated. These estimates include the cost of installation and demobilization. The vendor states that the amount and type of contaminant has little to do with costing. Factors listed as having the greatest impact on cost are:

- Quantity of impacted media
- Site accessibility
- Groundwater parameters at the site
- Depth of contamination
- Lateral contaminant migration
- Soil permeability/porosity (D17801S, p. 2; D18893G, p. 2; personal communication with vendor, 1/00)

Cost information provided by the vendor for full-scale applications of BIO-INTEGRATION technology is provided below.

Frankfort, Indiana. This project involved full-scale remediation of an leaking underground storage tank (LUST) site. The site contained 1238 tons of soil contaminated with total petroleum hydrocarbons (TPH). The area of contaminated soil was 27 by 55 ft across and 15 ft deep. TPH concentrations were reduced from 1200 parts per million (ppm) to nondetectable levels in 82 days. The cost of the project was $13,600. This cost included mobilization, demobilization, and in situ BIO-INTEGRATION treatment (D17796C, p. 1). This breaks down to approximately $11/ton of soil treated.

Roachdale, Indiana. This project involved the in situ treatment of 1184 tons of soil contaminated with TPH from a LUST. The cost of the project was $40,300. This cost included site characterization, mobilization, demobilization, in situ BIO-INTEGRATION, laboratory analyses, and closure documentation (D17796C, p. 2). This breaks down to approximately $34/ton of soil treated.

Bedford, Indiana. For this project, 1017 tons of soil contaminated with TPH from a LUST were treated using in situ BIO-INTEGRATION technology. The cost of the project was $27,000. This cost included mobilization, demobilization, treatment, sampling, laboratory analyses, and closure documentation (D17796C, p. 3). This breaks down to approximately $27/ton of soil treated.

Gulf Coast Petroleum Refinery. This project involved the cleanup of a crude oil spill in a wetlands area. Costs were estimated to be $2/ft^2 of area treated. Treatment included emergency response mobilization, demobilization, sampling, laboratory analyses, and treatment (D17796C, p. 4).

Petroleum Refinery. Since 1994, BIO-INTEGRATION technology has been used to treat a mixed-liquor wastewater at a Gulf Coast petroleum refinery. The cost of the treatment system is estimated to cost $200 to $300 per week, as compared to previous disposal costs of $3300 per week (D17796C, p. 6).

Information Sources

D17796C, Interstate Remediation Services, undated

D17801S, Interstate Remediation Services, 1998

D18893G, Environmental Remediation Consultants, Inc., 1997

T0278

Environmental Remediation International (EnRem), Ltd.

Soil Remediation System (SRS)

Abstract
EnRem has developed a soil washing system that recovers hydrocarbons for reuse. The unit uses a patented chemical, EnRem-17. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0279

Environmental Research and Development, Inc.

Neutral Process for Heavy-Metals Removal

Abstract
Environmental Research and Development, Inc., offers the neutral process, which reduces hexavalent chromium using sulfide catalyzed by ferrous iron, while precipitating heavy metals at pH ranges from 7.4 to 8.4. The vendor has combined this technology with cross-flow microfiltration to remove heavy metals from contaminated groundwater and wastewater without the need for large clarifiers. The technology has been used at U.S. Department of Defense (DOD) sites and is commercially available.

The vendor states that the technology could also be applied to acid mine drainage and can be effective on groundwater and wastewater streams containing chromium, cadmium, copper, lead, nickel, zinc, aluminum, mercury, gold, silver, cobalt, iron, arsenic, and strontium. The vendor claims the following advantages of neutral process technology:

- Eliminates the need for clarifiers, polymers, or flocculation aids.
- Allows for recycling of effluent water.
- Operates regardless of the presence of surfactant or chelating agents.
- Reduces chemical usage.
- Operates effectively as a batch or continuous process.
- Reduces operating costs.

The neutral process does not remove oil, other organics, or cyanide. However, the vendor states that the system can easily couple with systems that remove those contaminants. The technology produces a filter cake that must be treated or disposed of.

Technology Cost
The vendor states that neutral process technology is cheaper than existing technologies because systems do not require clarifiers, surfactants, or chelating agents (D18062L, p. 5).

The technology was demonstrated at the U.S. Department of Defense's (DOD's) Tobyhanna Army Depot in Pennsylvania. Under the existing treatment process at the site, chemical costs per year were approximately $4630 per year, and sludge disposal costs were approximately $9400 per year. Based on the performance of the pilot-scale unit, the projected costs for the neutral process were $623 per year for chemicals and $1560 per year for sludge disposal. The vendor

TABLE 1 Treatment and Disposal Costs for a Neutral Process NP-7000 Series Cross-Flow Microfiltration Membrane Heavy-Metal Wastewater Treatment System, Tobyhanna Army Depot[a]

Chemical	Usage per Year	Unit Cost	Cost (dollars/year)
Sodium metabisulfide	None	NA[b]	None
Sulfuric acid	30 gal	$3.50/gal	$105
ERF-60	96 lb	$02.9/lb	$28
ERS-150	156 lb	$1.00/lb	$156
Polymer	None	—	None
Caustic soda (50%)	30 gal (1 drum)	$115/drum	$115
Total chemical costs			$447
Sludge disposal costs	3000 lb	$0.729/lb	$2,187
Total			$2,634

Source: Adapted from D18062L.
[a]Costs are based on the treatment of 4,620,066 gal of wastewater during August 1993 through July 1994.
[b]NA, not applicable.

states that applying the neutral process to the site would reduce treatment and disposal costs at the site by over 70% (D18061K, p. 6). The treatment and disposal costs encountered at the Tobyhanna Army Depot demonstration are given in Table 1.

In 1997, neutral process systems were installed to treat chromium-contaminated groundwater and wastewater at the Marine Corps Logistic Base in Albany, Georgia. According to the vendor, the estimated cost savings for chemical usage and sludge disposal with this process were $116,500 or 47% when compared to the existing surfactant and clarifier system (D18061K, pp. 4–5).

The wastewater treatment plant at the DOD's Naval Undersea Warfare Center in Keyport, Washington, used a sulfur dioxide caustic process. In 1995, a full-scale neutral process system was installed to replace the existing wastewater treatment plant. The vendor estimated that the new system would save $31,950 annually (D187375, p. 2).

Information Sources

D18061K, Environmental Technology, 1998

D18062L, Environmental Research and Development, Inc., undated

D187375, Environmental Research and Development, Inc., undated

T0280

Environmental Research and Development, Inc.

Ice Electrode

Abstract

Environmental Research and Development, Inc. (ERAD), is researching ice electrode technology for the removal of metallic ions from contaminated groundwater and wastewater. The technology was originally developed by Idaho National Engineering Laboratory (INEL) and is based on electroplating technology. In ice electrode processing, a conventional electroplating electrode is coated with a thin layer of ice. Metals from the contaminated liquid are plated as small

particles onto the surface of the ice layer, where they can be removed by simply allowing the ice to melt. The process electrode is not damaged during operation. Proof-of-principle testing has shown that ice electrodes can remove copper, silver, zinc, cobalt, cadmium, lead, chromium, and tungsten ions from dilute aqueous solutions. Uranium dissolved in sulfuric acid was also removed by ice electrodes. The technology has been tested on the bench scale and is not currently commercially available.

The vendor claims the following advantages of ice electrode technology:

- The particulate nature of the trapped metal results in each growing crystal of metal becoming a microelectrode that enlarges the active surface area of the electrode. Thus the deposition rate is maintained as concentration of metals in solution declines.
- Metals are recovered in their pure form, and metal recovery is a simple matter of allowing the ice to melt.
- A fresh ice electrode surface is easily obtained by melting the ice and resuming treatment of the solution.
- Metals such as uranium and tungsten, which are difficult to electrodeposit, can be removed using ice electrode technology.

In treating samples with more than one metallic component, the metal with the greatest anodic reduction potential (metals most easily reduced by electricity) is the first to plate out onto the ice electrode, followed by the metal with the next highest potential. Difficulties have been encountered in maximizing current efficiencies. Presently, it appears that the technology would only be economical for high-value materials or wastes with high disposal costs.

Technology Cost

The cost of producing the ice surface limits the economics of ice electrode technology. In a 1996 evaluation of a bench-scale ice electrode system, an aqueous solution containing 2000 parts per million (ppm) copper sulfate was treated to determine operating parameters of the system. The vendor estimates that, with a current efficiency of 34%, it would take approximately 838 hr to produce a kilogram of copper. The total power requirement to produce 1 kg of copper using the bench-scale ice electrode system is 4206 kWh. At a cost of $0.10/kWh, the electrical cost of producing 1 kg of copper is $420. At 34% efficiency, a standard electroplating procedure could produce 1 kg of copper for $1.60 (D13692P, p. 21).

If the efficiency of the electrode could be increased to 95%, power costs would drop to $150/kg. If a more efficient cooler was used, and the amount of ice formed during treatment would be reduced, power costs could drop to as low as $75/kg. If the system was scaled-up by a factor of 8, it may be economical to cool the electrode using liquid nitrogen (D13692P, p. 21). Presently, it appears that the technology would only be economical for high-value materials or wastes with high disposal costs (D13692P, p. iii).

Information Source

D13692P, Beller et al., 1996

T0281

Environmental Resources Management Corporation (ERM)

Advanced Fluidized Composting (AFC)

Abstract

Advanced Fluidized Composting (AFC^{SM}) is an ex situ technology that combines aerobic and anaerobic biological treatment with a chemical treatment such as oxidation and hydrolysis.

Unlike conventional systems, the AFC uses thermophilic microorganisms that thrive in environments roughly 110 to 160°F.

According to the vendor, this technology reduces the volume of sludge that requires disposal and has successfully treated:

- Concentrated solvent streams, such as methanol, toluene, and benzene
- High-strength organic acids, such as salicylic and acetic
- Fermentation broths
- Waste activated sludges
- High-strength nitrate streams
- Phenolic and carboxylic acid streams
- Fats, oils, and greases
- Metal-stamping oil and grease

Several full-scale AFC units are currently in use, and this technology is currently commercially available.

Technology Cost
There is no available information regarding the costs associated with the advanced fluidized composting technology.

T0282

Environmental Soil Management, Inc.

Low-Temperature Thermal Desorption

Abstract
The Environmental Soil Management, Inc. (ESMI), low-temperature thermal desorption (LTTD) process is an ex situ, thermal technology that treats soils contaminated with petroleum and nonpetroleum hydrocarbons. LTTD heats contaminated waste material in a rotary dryer to temperatures between 500 and 800°F. Contaminants are volatilized and destroyed in a thermal oxidizer. The treated soil becomes the property of ESMI or is returned to the client for reuse.

The vendor states that the technology has been used in full-scale applications and is commercially available.

According to the vendor, LTTD technology has several advantages:

- Allows for verifiable cleanups of contaminated soil.
- Eliminates long-term liability by destroying organic contaminants.
- Applies to a wide variety of volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs).
- Treats all soil types, including silt and clay.
- Allows a site to be quickly returned to the client for reuse.

Soils with high moisture or clay contents may reduce the efficiency of the LTTD system. “Hot spots” in the influent soils may cause fluctuations in the dryer temperature. The vaporized hydrocarbon concentration in the kiln must be kept below the lower explosive limit (LEL).

TABLE 1 Cost Information for Full-Scale Remediation Applications

Site or Client	Contaminants	Amount of Soil Treated (Tons)	Type of Treatment	Cost ($)	Cost-Related Comments
American Thermostat Superfund Site, South Cairo, New York	TCE[a] PCE[b]	~50, 000	On-site	2,100,000	Thermal treatment costs
Harbor Point MGP[c]	Coal tar	106	FFTNH[d]	9,000	Thermal treatment and transportation costs
American Waste Systems	Waste oil, PCBs[e]	2,300	FFTNH	115,000	Total project costs
Former Naval Waste Oil Landfill	TPH,[f] PCBs	5,700	FFTNH	350,000	Total project costs
Rutland Regional Transit Center	Gasoline, no. 2 heating oil	3491.49	FFTNY[g]	120,000	Transportation and treatment costs
Former MGP	TPH, PAHs[h]	285	FFTNH	30,000	Transportation and treatment costs
Utility Company's Service Center	Gasoline, PCBs	9,252	FFTNY	415,000	Transportation and treatment costs
Gilson Road Tar Pits	Tar-oil emulsions	2,335	FFTNH	156,000	Total project costs
Dart Industries	PCBs, waste oil	16,000	FFTNH	600,000	Total project costs

Source: Adapted from D22644I.
[a]Trichloroethene.
[b]Tetrachloroethene.
[c]Manufactured gas plant.
[d]Fixed Facility Treatment, New Hampshire
[e]Polychlorinated biphenyls.
[f]Total petroleum hydrocarbons.
[g]Fixed Facility Treatment, New York
[h]Polycyclic aromatic hydrocarbons.

Technology Cost

According to the vendor, the cost for LTTD treatment ranges from $50 to $100 (1995 dollars) per ton of waste material. It was not stated that this estimate included all indirect costs associated with treatment such as excavation, permits, and treatment of residuals (D10409W, p. 13).

Factors that have a significant effect on treatment costs include the following:

- Quantity of waste
- Amount of debris with waste
- Site preparation
- Initial contaminant concentration
- Characteristics of soil

- Waste handling/preprocessing
- Moisture content of soil
- Characteristics of residual waste (D10409W, p. 13)

The vendor states that LTTD has been used during several full-scale remediation applications. Contaminated soils have been treated using the on-site and fixed-facility LTTD equipment (D22644I). On-site treatment costs were approximately $42 per ton. Treatment costs for the fixed-facility applications ranged from approximately $35 per ton to $105 per ton. The cost data is summarized in Table 1.

Information Sources

D10409W, VISITT Version 4.0, 1995
D22644I, Environmental Soil Management, Inc., undated

T0283

Environmental Solutions, Inc.

CHEM-STA

Abstract
The Chemical Stabilization Technology (CHEM-STA™) is a proprietary contaminant immobilization mechanism for treating soils, sludges, and ashes contaminated with toxic heavy metals and hydrocarbons. The three-step process can be applied either in situ or ex situ to form stable and insoluble chemical compounds. Treated wastes are usually acceptable for landfill disposal. This technology is commercially available from Environmental Solutions, Inc. (ESI).

According to the vendor, CHEM-STA has the following advantages:

- Reagents are easy to use.
- Reagents are nontoxic to the environment.
- Process is cost effective.

The CHEM-STA process can be limited by the presence of oxiders, such as chlorine, peroxide, permanganate, or persulfate. The presence of cyanide or chromium in waste can also create treatment limitations. All of the information provided in this summary is based on vendor literature and has not been independently verified.

Technology Cost
According to the vendor, the trithiocarbonate agent used in the first step of the CHEM-STA process costs less per pound of metals treated than dithiocarbamate (an alternative precipitant) (D22428C, p. 7).

Information Source

D22428C, Environmental Solutions, Inc., undated

T0284

Environmental Technology (U.S.), Inc.

CPU-MOD/T

Abstract
Environmental Technology (U.S.), Inc. (ETUS), has developed the CPU-MOD/T treatment system for the ex situ removal or recovery of wastewater contaminated with heavy metals. The

system operates in a continuous batch fashion and can be operated as a permanent or transportable unit. During processing, a combination of process chemicals and electrode technology are used to remove heavy metals as a precipitant. The technology has been used commercially in California, as well as in the northeastern and midwestern United States. The CPU-MOD/T technology is no longer commercially available.

The vendor claims the advantages of the CPU-MOD/T system are that minimal operator attention is required, that CPU-MOD/T is a time-tested technology, that no filter press is required, and that discharge criteria are met.

All information in this summary was supplied by the vendor and has not been independently verified.

Technology Cost
No information available.

T0285

Environmental Technology (U.S.), Inc.

TR-Detox

Abstract
Environmental Technology (U.S.), Inc. (ETUS), has developed the TR-Detox stabilization and detoxification technology for the treatment of soils contaminated with heavy metals and radionuclides. The technology can be used for in situ and ex situ applications, using a synergistic combination of specific reagents to reduce heavy metals to their lowest valence state, and allow them to form insoluble organometallic complexes. The vendor claims that the created organometallic complexes are leach resistant and tend to increase in stability over time. The vendor claims the technology can be used in conjunction with biological treatment for the destruction of organic contaminants. The technology is commercially available in the United States and has been used for many remediation applications.

ETUS claims the following advantages of TR-Detox:

- Improved performance (treated soil is actually detoxified, not just stabilized)
- Minimal volume increase (as compared to cement stabilization technologies)
- Lower costs (typically one-third to one-half the cost associated with traditional treatment technologies)

Treatability studies are required prior to applications of TR-Detox technology. Treatment is not pH dependent, however, a pH of 8.5 is recommended if the process is used for polishing procedures. A sulfur odor is associated with TR-Detox treatment, but this can be minimized by pretreatment and proper dosage of process chemicals.

Technology Cost
In 1995, the vendor supplied information to the VISITT database, estimating that TR-Detox technology treatment costs range from $20 to $50 per ton of contaminated material treated. Factors listed as impacting costs are (in decreasing order of importance) initial contaminant concentration, the target contaminant concentration, the quantity of wastes, the moisture content of the soil, site preparation, waste handling and preprocessing requirements, depth of contamination, depth to groundwater, characteristics of the residual wastes, characteristics of the soil, amount of debris associated with the waste, labor rates, utility and fuel rates, and weather conditions (D10103H, p. 38).

During a field demonstration of TR-Detox technology applications to chromium ore processing residue for the Port of Baltimore, treatment costs were estimated at $25 per ton. The field demonstration included in situ and ex situ treatment of contaminated soil and sediment, sludge treatment, and in situ treatment of groundwater (D10103H, pp. 13–17).

During a full-scale remediation of a pulp and paper industry wood preserving site in California, cleanup costs were estimated at $50 per ton. The remediation included in situ treatment of soil, sediment, and groundwater (D10103H, pp. 18–22).

During a full-scale remediation of 10,000 tons of contaminated soil and sludge at a Louisiana petroleum refining facility, costs were estimated at $40 per ton. The cleanup involved of both in situ and ex situ techniques (D10103H, pp. 23–15).

Information Source

D10103H, VISITT 4.0, 1995

T0286

Environmental Treatment and Technologies Corporation

Methanol Extraction Process

Abstract
This is a methanol extraction process in which a methanol solution is used to extract organic contaminants from soils. RIMS was unable to contact the vendor, therefore commercial availability is unknown. The technology was demonstrated in 1986 through a U.S. Environmental Protection Agency Region III sponsored cleanup in Minden, West Virginia.

The contaminated sediment is crushed to a size range suitable for drying. The sediment is then dried to a water content of 5%. The airflow is run through pollution controls to remove particulate emissions. The recovered fines material is subjected to methanol extraction along with the dried sediments. The cleaned sediment is then subjected to another drying process.

In the only example available of the methanol extraction process, the treatment goals were not met. A bioremediation landfarming method was used for further reduction. It has been suggested that repeating the extraction process could increase contaminant reduction.

The drying operation contributes to the cost and creates the need for pollution controls, particulate recovery, and handling of the particulates as a toxic waste.

Technology Costs
No available information.

T0287

Environmental Tune-Up, Inc.

Apollo Oil–Water Separator

Abstract
The Apollo oil–water separator technology is designed for the separation of water streams containing immiscible hydrocarbons. It is applicable for oils that are either heavier or lighter than water, so long as the density difference is greater than 1%. The vendor claims that this technology can handle streams containing from zero to nearly 100% oil in water or water in oil.

The Apollo technology uses a patented separation media, which is designed to force a rapid rate of coalescence, speeding the separation of oil and water dramatically without using heat,

chemicals, or settling tanks. The vendor claims that this technology can clean water contaminated with a variety of hydrocarbons, as long as they are immiscible in water.

In 1998, Environmental Tune-Up, Inc., closed after default of its main technology supplier. As of October, 1998, the company was prosecuting with the City of Houston against the inventor for misrepresentation and fraud (personal communication with Michael Mandeville, Environmental Tune-Up, 1998).

Technology Cost

There is no available information regarding the costs associated with this technology.

T0288

Enviro-Sciences, Inc.

Low-Energy Extraction Process (LEEP)

Abstract

The patented, Enviro-Sciences, Inc. (formerly ART International, Inc.) Low-Energy Extraction Process (LEEP™) is a low-pressure process that uses common organic solvents to concentrate and extract primarily polychlorinated biphenyls (PCBs), coal tar, and related compounds from soil, sediments, and sludge. The LEEP technology uses pretreatment, washing, and concentration phases. The process operates under ambient conditions and can treat contaminated solids to cleanup levels mandated by regulatory agencies. However, the LEEP process cannot treat heavy metals. The technology can treat matrices containing particle sizes down to the submicron range and matrices containing as much as 90% water.

Technology Cost

According to WASTECH, the LEEP technology treatment cost ranges from \$95 to \$300/ton (\$105 to \$330/metric ton) (D12827I, p. 5.3). Unit costs for the LEEP technology include operating costs, capital costs, mobilization/demobilization costs, and quality assurance/quality control site management costs (D12439A, p. 1).

Information Sources

D12439A, Water Technology International Corporation, September 12, 1996

D12827I, WASTECH, 1995

T0289

EnviroSep, Inc.

Thick-Film Absorption

Abstract

EnviroSep, Inc. (EnviroSep), has developed a thick-film absorption technology for the removal of volatile organic compounds (VOCs) from water. The technology uses a proprietary form of silicone rubber to absorb contaminants. The vendor claims the technology is effective for VOCs with less than 2% solubility in water and a boiling point of less than 200°C for the pure compound and is most efficient for use at sites with contaminant concentrations between 10 parts per million (ppm) and 2000 ppm. The technology is intended for aqueous waste streams.

As of 1997, the firm was conducting evaluations of the technology for oil and petrochemical industry applications, and expected to begin selling systems in 1998.

The vendor claims that the performance of the unit is unaffected by dissolved salts, suspended solids, acids and bases, or soluble organics content. They also claim that system removal of units operated in series can exceed 99.9% and that treatment rates of up to 500 gal/min are possible.

The vendor claims pilot testing of the procedure has demonstrated removal of benzene, xylene, hexene, styrene and trichloroethylene from water, with no performance decline in 7 months of continuous operation.

Technology Cost

In 1997, EnviroSep, Inc. (EnviroSep), estimated the capital and operating costs of a thick-film absorption system would be approximately $4.50 per 1000 gal of water treated.

For the purposes of the estimation, it was assumed that the system treated water contaminated with 300 ppm benzene, toluene, and gasoline hydrocarbons, at a flow rate of 20 gal/min, using an activated carbon polishing step to an effluent concentration of 5 parts per billion (ppb) (D16385T, p. 1).

Information Source

D16385T, HazTECH News, 1997, web page

T0290

Enviro-Soil Remediation, Inc.

Thermal Stripping

Abstract

Enviro-Soil Remediation, Inc. (Enviro-Soil), is the owner of the thermal stripping thermal desorption system. This ex situ technology uses a combination of a low-temperature primary treatment chamber and a secondary high-temperature treatment chamber to remove petroleum hydrocarbons from contaminated soil. As of 1995, the thermal stripping system had been applied in three full-scale commercial cleanups. According to the vendor, the technology is not currently in use. The vendor is no longer involved in remediation work and has become involved in consulting instead.

The vendor claims that the thermal stripping system treats soil contaminated with gasoline, diesel fuel, or kerosene, at prices equal to or lower than those using off-site incineration or landfarming. They also state that the system has the potential to treat chlorinated and fluorinated hydrocarbons.

If the soil has a high water content, treatment rates are decreased. All information presented in this summary was provided by the vendor and has not been independently verified.

Technology Cost

In 1995, Enviro-Soil Remediation, Inc. (Enviro-Soil), estimated that treating contaminated soil using its thermal desorption technology would cost between $25 and $45 per ton. This estimate stated that price estimates may not include all indirect costs associated with treatment, such as excavation, permits, and treatment of residuals. Factors listed as having a significant effect on costs include (in decreasing order of importance): depth to groundwater and utility/fuel rates, labor rates, site preparation costs, the initial contaminant concentration, the amount of debris associated with the waste, the characteristics of the soil, quantity of waste, waste handling and preprocessing costs, the characteristics of the residual wastes, the depth of the contamination, the moisture content of the soil, and the target contaminant concentration (D10119P, p. 1).

Information Source

D10119P, VISITT 4.0, 1995

T0291

EnviroSource Technologies

Super Detox Process

Abstract

EnviroSource Technologies, formerly EnviroSource Treatment and Disposal Services, Inc., has developed the Super Detox® stabilization process for the treatment of electric arc furnace dust (EAF dust). This dust is generated during steel production. The Super Detox process is specifically designed for low-zinc wastes EAF dusts (less than 15% zinc by weight). Super Detox technology stabilizes the ash by multiple reaction mechanisms, including oxidation/reduction, metals insolubilization, silicate polymerization and substitution, and pozzolanic bonding and solidification. The technology is commercially available.

EnviroSource Technologies claims the following advantages of the Super Detox system:

- Treatment residuals meet strict land disposal restrictions or delisting requirements.
- Single point of disposal for treated EAF dust.
- Low cost compared to other technologies.
- Lowest available toxicity characteristic leaching procedure (TCLP) leachate levels for any process treating EAF dust.
- Lower volume of the final waste form when compared to competing technologies.

This summary is based on vendor information that has not been independently verified.

Technology Cost

Information published by EnviroSource Technologies, formerly EnviroSource Treatment and Disposal Services, Inc., in 1991 stated that Super Detox technology costs would range from \$110 to \$145 per ton of electric arc furnace dust. This estimate included all processing services, including capital investment, return on capital, operating labor, additives, and off-site landfilling. These costs would significantly reduced if the steel mill had an on-site Subtitle Class-D landfill (D14482L, p. 582).

According to the vendor, several factors of the Super Detox process limit processing costs. A low additive ratio reduces additive and disposal costs. The process has low energy requirements and can be custom designed for specific client needs (D15456N, p. 9).

Information Sources

D14482L, Hilton and Lynn, 1993
D15456N, EnviroSource vendor literature, 1995

T0292

EnviroWall, Inc.

EnviroWall Barrier

Abstract

The EnviroWall™ system is an in situ barrier technology designed to isolate areas of an underground contaminant plume for treatment. EnviroWall is a composite cutoff wall that is formed

by using a guide box to insert a synthetic high-density polyethylene (HDPE) geomembrane into the trench of a slurry wall. The interlocking polyethylene panels form an impermeable subterranean wall that prevents the flow of contaminated groundwater or leachate. EnviroWall may be used to contain a contaminant plume, as a funnel to direct a plume toward a treatment cell, or as a permeable reaction wall to treat contaminants in situ. This technology is commercially available and has been demonstrated in the field.

According to the vendor, some advantages of the Envirowall system are:

- Has minimal number of joints.
- Is unaffected by fluctuations in the water table.
- Is very adaptable and can be used with multiple treatment systems.
- Can be installed in trenches as narrow as 24 inches.
- Has an interlock system that quickly ensures a tight seal.

EnviroWall is a barrier. It serves to isolate contaminants and must be combined with another technology to treat contaminants. According to the vendor, EnviroWall barriers can be installed to a maximum depth of 50 ft. The presence of boulders in the subsurface will increase treatment costs. The long-term durability of the HDPE material is not known. The system is best suited to treat contaminated groundwater and leachate at depths up to 50 ft when the contaminated media is underlain by an aquitard or other impermeable layer.

Technology Cost

The cost of the HDPE used in the Envirowall system ranges from \$10 to \$30/ft^2 (D20300P, p. 25).

Table 1 shows the estimated installation costs of a funnel-and-gate system using the Envirowall barrier technology. The presence of boulders in the subsurface will increase installation costs (D18981F, p. 22).

Information Sources

D18981F, Pearlman, 1999
D20300P, Pearlman, 1999

TABLE 1 Estimated Installation Costs for an Envirowall Funnel-and-Gate System

Depth (ft)	Cost of 100-Ft Wingwalls ($)	Cost of 500-Ft Wingwalls ($)
8	47,426.00	103,178.00
11	59,269.20	132,862.00
14	71,670.00	165,333.20
17	85,185.60	203,380.00
20	100,559.60	250,718.40
23	116,863.20	302,703.20
26	138,184.00	379,776.00
29	155,905.20	456,849.20
32	180,826.00	553,922.00
35	202,147.20	610,995.20

Source: From D18981F.

T0293

Enzyme Technologies, Inc.

Dissolved Oxygen In situ Treatment (DO-IT)

Abstract

Enzyme Technologies, Inc., has developed an aerobic bioremediation technology called the dissolved oxygen in situ treatment (DO-IT) system. This system cycles nutrient- and bacteria-enhanced, superoxygenated water through a contaminated zone to degrade contaminants in situ. DO-IT is a commercially available technology that can be used independently or in conjunction with existing pump-and-treat, air sparging, or vapor extraction systems. It is often used with other Enzyme Technologies, Inc., products including multienzyme complexes (EZT-MZC), enzyme accelerator (EA), TPH bacterial consortium (EZT-A2), and custom blend nutrients (EZT-CBN).

DO-IT has been used at several sites to treat benzene, toluene, ethyl benzene, and xylene (BTEX), methyl *tert*-butyl ether (MTBE), and total petroleum hydrocarbons (TPH). According to the vendor, this technology may also be applied or modified to clean up any aerobically biodegradable contaminants in soil.

Technology Cost

According to the vendor, oxygen production costs for the DO-IT system are approximately $25 to $50/lb (D17794A, p. 1). The vendor also claims that other treatment methods can be up to 14 times more expensive than the DO-IT Model 10 system (D203554, p. 4).

Information Sources

D17794A, Enzyme Technologies, Inc., 1998

D203554, Enzyme Technologies, Inc., undated

T0294

Enzyme Technologies, Inc.

Multienzyme Complex (MZC)

Abstract

Enzyme Technologies, Inc., multienzyme complex (MZC) process is a biological remediation technology for soils and water contaminated with organic compounds, such as petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), and methyl tertiary butyl ether (MTBE). The technology was developed using microorganisms that were able to survive in highly contaminated media. The Enzyme Technologies, Inc., process removes useful enzymes and surfactants (compounds that make contaminants easier to degrade) from these microorganisms and applies them directly to the contaminated media. This technique speeds up remediation time compared to conventional biological methods that use the entire microorganism to degrade contaminants.

The MZC process has been used in full-scale applications and is commercially available. It can be applied ex situ or in situ. A common application of this technology is landfarming, in which contaminated soils are placed in cells, the soils are mixed and aerated, and MZC products are added. Treatment times depend on the level and type of contamination, and the ease with which the soil can be worked. Higher contamination levels require more time, as do soils with higher clay concentrations. According to the vendor, sandy soils or moderate contamination

levels may be remediated in approximately 15 to 45 days, while heavier soils or contamination levels may take approximately 60 to 150 days.

Technology Cost

For a pilot study conducted at Thule Air Force Base in Greenland, MZC costs were estimated to be $\$105/yd^3$ of soil treated. This estimate included expenses associated with landfarm construction, soil inoculation, tilling, and sampling. The vendor notes that the costs of additional treatment at the site would be 25% lower than this estimate due to the economies of scale. According to the vendor, ex situ MZC costs for comparable sites on the mainland United States would range from \$25 to $\$35/yd^3$ yard (D19594C, p. 11).

The MZC technology was less expensive than alternative technologies considered at the Greenland site. For example, thermal treatment would have cost between \$250 and $\$275/yd^3$. This elevated cost was partially due to the expense of transporting equipment to Greenland. According to the vendor, conventional bioremediation techniques would have cost between \$175 and $\$200/yd^3$ at the Greenland site (D19594C, p. 11).

Information Source

D19594C, Clark, 1999

T0295

EOD Technology, Inc.

Biotechnical Processing of Explosives

Abstract

Biotechnical processing of explosives is a commercially available, ex situ biological treatment technology used primarily to treat soils and liquids contaminated with TNT, napalm, nitrocellular, nitroglycerin, single- and double-base propellants, and other explosives as well as trichloroethene (TCE), halogenated hydrocarbons, volatiles, and semivolatiles. The technology utilizes amoeba–bacteria consortia and a biodispersant. The biodispersant enhances biodegradation by stimulating indigenous bacteria.

Slurry-phase biodegradation or other methods are used, depending on the nature of the contamination. For slurry-phase treatment, the company offers a mobile biotechnical processing unit that the vendor claims is capable of degrading explosives and explosive wastes in soil or water or as pure compounds.

The amoeba–bacteria consortia used, although highly resistant to environmental conditions, are vulnerable to metal ions, especially chromium, copper, and similar highly oxidized ions. The biodispersant is effective in degrading organic contaminants, but no testing has been done to evaluate its efficiency in removing inorganic contaminants. Since this is a biological remediation process, it is unlikely that inorganics would be treatable with this process. Before any field application of the process, some batch experiments are performed with the samples to establish field protocols.

Technology Cost

According to vendor-supplied information, the cost ranges from \$300 to \$1200 per ton of waste treated. This estimate does not include all indirect costs associated with treatment, such as excavation, permits, and treatment of residuals (D10109N, p. 21).

Information Source

D10109N, U.S. EPA, 1995

T0296

EPG Companies, Inc.

Oxidair Thermal Oxidizers

Abstract
The Oxidair™ Model EH thermal oxidizer is a horizontal forced-draft flume thermal oxidizer for destroying hydrocarbon vapors. The standard unit consists of a burner, combustion chamber, exhaust stack, pipe trains for auxiliary fuel and fume stream, draft air fan, and controls.

According to the vendor, specifications for the Oxidair Model EH thermal oxidizer include the following:

- Operating temperature of 1400°F with 0.5-sec residence time.
- Destruction rate in excess of 99.9%.
- Auxiliary burner turndown range of 4:1.
- Carbon steel construction with internal insulation.
- Factory-mutual style pipe train for natural gas or liquefied petroleum gas (LPG), which branches to provide fuel to the pilot as well as the burner.
- Factory-mutual style pipe train for hydrocarbon vapors.
- Unit Prepiped, wired, and tested before shipping.
- vapor concentrations vary from 0% lower explosive limit (LEL) through and above the explosive range (100% LEL).

This technology is currently commercially available.

All information is from the vendor and has not been independently verified.

Technology Cost
According to the vendor, depending on actual flow rate and fume stream concentrations, a typical thermal oxidizer for a hydrocarbon remediation site would cost $25,000 to $40,000 (1997 dollars). Rental rates would be approximately $3000 to $4500 per month (personal communication: Jim Bailey, EPG Companies Inc., 1997).

T0297

EPOC Water, Inc.

Microfiltration Technology (EXXFLOW and EXXPRESS)

Abstract
The EPOC microfiltration process is based on the ability of a proprietary woven polyester filter to retain particles and allow water to permeate through the filter. The technology uses a three-step process in which: (1) reagents are added to the wastewater to precipitate metals and/or sorb other contaminants; (2) the microfiltration unit (known as EXXFLOW) removes and concentrates the precipitates, while allowing water (permeate) to pass; and (3) the concentrated precipitate is dewatered (by a module called EXXPRESS) to produce a semidry filter cake containing the metal precipitates and other filtered solids.

The EPOC microfiltration process has been commercially available since 1989. The technology has been used in full-scale applications. The vendor states that treatment systems have been installed at over 45 sites worldwide.

According to the vendor, the EPOC microfiltration technology offers several advantages:

- Produces higher quality treated water than traditional membrane filtration processes.
- Uses fewer chemicals than traditional membrane filtration processes.
- Is readily expandable and has a higher throughput than traditional membrane filtration processes.
- Uses a durable membrane that can be easily cleaned.
- Tolerates flow variations.

The liquid waste must be pumpable. Contaminants must be in particulate form, or it must be possible to precipitate dissolved contaminants such as metal ions chemically. Separation must provide an advantage. The EPOC microfiltration technology does not remove volatile organic compounds (VOCs) from liquids. The unit's operation is affected by cold weather.

Technology Cost

The costs of the EPOC Water, Inc. (EPOC) microfiltration technology are affected by system flow rates, amount of recycle, contaminant type and concentration, reagent type and amount, and the type and size of dewatering equipment used (D11314U, p. 15).

In 1995, the U.S. Environmental Protection Agency (EPA) prepared cost estimates for the EXXFLOW process based on the Superfund Innovative Technology Evaluation (SITE) demonstration. Treatment costs using a 7 gal/min (gpm) EXXFLOW unit were estimated at $103 per 1000 gal of water treated. The treatment costs decrease to about $47 per 1000 gal for a 50-gpm unit. Chemical cost is a major factor with both units, but such costs decrease significantly on scaleup. The costs for both units were developed with a conventional filter press for dewatering, because the EXXPRESS unit could not be operated effectively during the SITE demonstration (D11314U, pp. 7, 17). Table 1 displays the cost estimates prepared by the EPA.

A 10- to 15-gpm EXXFLOW unit and an EXXPRESS unit producing 50 gal of filter cake per day were installed to remove pesticides, heavy metals, and oils from rinse liquid produced by FMC Corporation in Fresno, California. Capital costs were approximately $175,000. Equipment installation cost $12,000 (D11314U, p. 43).

In 1991, an EXXFLOW/EXXPRESS system was combined with an air stripper to remediate groundwater contaminated with chromium and trichloroethene (TCE) beneath an abandoned manufacturing plant in Newbury Park, California. System equipment cost approximately

TABLE 1 Cost Estimates for EXXFLOW Units

	Cost ($)	
Cost Factor	Pilot-Scale, 7-gpm Unit	Full-Scale, 50-gpm Unit
Site preparation	31,000	33,500
Equipment (annualized)	6,500	17,400
Startup and fixed	25,650	91,350
Labor	84,000	84,000
Consumables and supplies	101,750	690,900
Utilities	3,145	6,775
Effluent treatment and disposal	90,385	67,420
Residuals/waste shipping, handling, and transport	8,600	61,780
Total	328,065	1,076,090

Source: Adapted from D11314U.

$150,000. Installation costs were $12,000. Operating costs included an estimated $0.25 per 1000 gal for electrical power and $0.02/gal for chemical consumption (D11314U, p. 44).

Information Source

D11314U, U.S. EPA, 1995

T0298

Eriksson Sediment Systems, Inc.

Eriksson System

Abstract

The Eriksson System is an in situ sediment removal technology designed to remove and dewater hazardous marine and aquatic sediments particularly those containing polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and other hydrocarbons, heavy metals, and radioactive materials. According to the developer, this technology may be used in both still and flowing water columns. The technology utilizes refrigeration to freeze sediments in situ into solid blocks by mean of self-contained freezing cells. The cells allow for the selective removal of only contaminated regions of sediment, minimizing the volume of material that will need further treatment or disposal.

A bench-scale demonstration of this technology was conducted at the Port Hope Harbor on Lake Ontario, 100 km east of Toronto. According to the vendor, full commercialization of the technology is being delayed due to a lack of capital financing.

All information is from the vendor and has not been independently verified.

Technology Cost

According to the vendor, costs for sediment removal, dewatering, water treatment, and segregation by particle size are approximately $250/m^3$ or less. For removal only, costs are $100/m^3$ or less. These estimated costs do not include mobilization and demobilization and/or supplying temporary enclosures (used in pretreatment) if none are available at the site (personal communication: Roger Carr, Eriksson Sediment Systems, Inc., May, 1997).

T0299

ETG Environmental, Inc.

Therm-O-Detox Medium-Temperature Thermal Desorption

Abstract

Therm-O-Detox™ is an ex situ system designed to remove contaminants from soils, sediments, and sludges, using a nonoxidative, medium-temperature thermal desorption process. The mobile Therm-O-Detox system heats the contaminated medium indirectly to desorb contaminants, which are later recovered from sweep gases.

This technology can remove oily sludges, pesticides, herbicides, pentachlorophenol, polychlorinated biphenyls (PCBs), coal by-products, wood treating compounds, dioxins, and furans. It is often used in conjunction with the company's base-catalyzed decomposition (BCD) process. The BCD process is designed to treat chlorinated compounds.

The patented Therm-O-Detox and BCD technologies have been used in full-scale cleanups. Both technologies are commercially available from ETG Environmental, Inc.

According to the vendor, the Therm-O-Detox system has the following advantages:

- Reduces treatment time.
- Treats soils, sediments, and sludges.
- Allows for on-site treatment.
- Treats high contaminant concentrations.

Thermal desorption technologies do not destroy contaminants. Contaminants require additional treatment or disposal.

Technology Cost
According to the vendor, the processing costs for the Therm-O-Detox system normally range from $150 to $250 per ton of soil treated. This estimate applies to the treatment of over 10,000 yd^3 (15,000 tons) of soil (D14598W, p. 219; D14610B, p. 4).

ETG supplied thermal desorption technology at the Southern Maryland Wood Treating Superfund site. From 1997 through 2000, it was estimated that the thermal desorption costs at the site were $60,450,429 (including pending costs and potential modifications). The estimated completion cost for this application was $221 per ton. This was within 4% of the estimated cost in the record of decision (ROD) ($214 per ton) (D22906L, p. 20).

The vendor supplied cost information for two sites. ETG states that 20,000 tons of soil contaminated with high-boiling-point, chlorinated volatile organics were successfully treated using Therm-O-Detox technology. The total cost of thermal treatment and recycling of the soil was $3,700,000 ($185 per ton of soil). At another site, ETG Environmental performed excavation, thermal desorption, backfill, and capping of a lagoon containing over 32,000 tons of organic-contaminated soil. The cost at this site was $240 per ton, totaling $7,700,000 (D14611C, p. 1).

Information Sources

D14598W, Shieh, undated
D14610B, Shieh and Bacskai, 1994
D14611C, ETG Environmental, undated

T0300

ETUS, Inc.

Enhanced Bioremediation

Abstract
ETUS, Inc. (ETUS), has developed an enhanced bioremediation technology that uses ETUS's CNP-PLUS biological activator solution. The technology can either be applied in situ or ex situ.

The treatment process converts from an anaerobic state to an aerobic state as higher carbon chain substances are metabolized under process control in a leach-proof envelope or Bio-Cell. The shorter carbon chain substances are then processed in an aerobic environment.

According to the technology developer, the technology can treat soils, sludges, and dredged sediments contaminated with organic contaminants ranging from diesel fuel to polychlorinated biphenyls (PCBs).

The technology developer claims that the technology is applicable for treating hydrocarbon soil contamination (caused by parking lot runoff, truck pads, accidental oil spills, fuel and coolant spills, machine and cutting oils, etc.), fuel storage areas, ponds, septic tanks, sumps, and loading docks. Additionally, the technology developer claims that the technology has been used

in the following industries: electroplating, gasoline/service station, herbicide manufacturing/use, machine shops, petroleum refining and reuse, other organic and chemical manufacturing. The technology can potentially be applied in these industries: agriculture, coal gasification, dry cleaning, industrial landfills, inorganic/organic pigments, municipal landfilling, paint/ink formulation, pesticide manufacturing/use, plastics manufacturing, pulp and paper industry, and semiconductor manufacturing.

Among the advantages listed by the technology developer are:

- Nontoxic characteristics of the CNP-PLUS reagent
- Ability of the CNP-PLUS reagent to improve both composting and aerobic systems

The developer lists the following limitations for the technology:

- Soils that contain metal contaminants require simple pretreatment conditioning.
- System requires a sustained ambient air temperature of less than 50°F.

Technology Cost

The technology developer claims that the technology costs \$20 to \$40/yd^3 to use. According to the technology developer, the technology can treat soils, sludges, and dredged sediments contaminated with organic contaminants at approximately 30% of the cost of thermal destruction or incineration (D10104I, pp. 2, 33).

The technology was used in remedial operations at the following sites (see Case Study overview):

- Railroad Service Station (Hudson, NJ)—cost \$29/yd^3 (total project cost of \$350,000) to remediate 12,000 yd^3 of soil and sediment (both ex situ).
- Petroleum Refinery (Lake Charlie, LA)—cost \$46/yd^3 (total project cost of \$92,000) to treat 2000 yd^3 of soil (ex situ) and sludge.
- Industrial Landfill (Memphis, TN)—cost \$46/yd^3 (total project cost of \$161,000) to remediate 3500 yd^3 of soil (ex situ).
- Chemical Company (Baton Rouge, LA)—cost \$35/yd^3 (total project cost of \$7,000) to remediate 200 yd^3 of soil (ex situ) (D10104I).

The following factors affect the cost for using the technology:

- Amount of debris in material to be treated
- Site preparation
- Waste handling/preprocessing
- Depth to groundwater
- Initial contaminant concentration
- Waste quantity (D10104I, p. 33)

Information Source

D10104I, VISITT 4.0

T0301

Evaporation for Wastewater Treatment — General

Abstract

In the evaporation process, wastewaters from metal finishing processes are heated until water vapor is formed. The water vapor is continuously removed and condensed. In this manner,

clean water is recovered and the solutes contained in the original wastewater are concentrated. The solutes may be waste materials or useful chemicals or reagents, such as copper, nickel, or chromium compounds, which may be recycled for further use. Evaporation is an established technology, and packaged evaporators are available from a number of suppliers.

When wastewaters contain volatile organics with boiling points that coincide with that for water, product condensate can be contaminated with organics. Removing these organics may require further treatment, consisting of a carbon bed or other polishing process. Other problems that may occur include foaming, scaling, fouling, and corrosion. Addition of pretreatment chemicals may be useful to reduce scaling and fouling.

Technology Cost
No available information.

T0302

Excimer Laser-Assisted Destruction of Organic Molecules — General

Abstract
Excimer laser-assisted destruction of organic molecules is used to treat vapor-phase benzene, toluene, ethylbenzene, and xylenes (BTEX) produced from air stripping of contaminated groundwater. One application of this technology has been to enhance the performance of high-temperature incineration of organic contaminants.

This technology has been tested at the laboratory-scale level.

Technology Cost
No available information.

T0303

Vendor unknown

Extraksol

Abstract
The Extraksol™ process is a batch, solvent extraction technology that extracts organic contaminants from unconsolidated solids. The Extraksol system is mobile, offering flexibility in treating soils and sludges to different decontamination levels.

The Extraksol process can extract organic contaminants such as oils and greases, polynuclear aromatic hydrocarbons (PAHs), pentachlorophenols (PCPs), and phenols from a variety of solid matrices. The Extraksol process can extract polychlorinated biphenyls (PCBs) from clay-bearing soil, sand, and Fuller's earth. Extraksol has successfully treated various media such as activated carbons, refinery sludges, and wood treatment sludges.

A major advantage of the Extraksol process is that it provides a fast, efficient, and versatile alternative for treatment of PCB-contaminated soil and sludge.

Currently, the Extraksol technology is inactive. A company named CET Environmental Services — Sanivan Group originally owned the technology. In 1991, some company employees, through a management buy out, purchased the decontamination and remediation unit of the company and renamed the new company Sanexen Environmental Services, Inc. (Sanexen). Sanexen did not purchase the Extraksol technology, however. As a result of the high costs associated with the use of flammable solvents in the Extraksol process, and additional safety measures because of the solvents, the company deemed the technology to be too costly to operate and to maintain. The high costs also prevented the Extraksol technology from competing effectively with less expensive forms of remediation. Sources have indicated (not verified) that the equipment previously used in the Extraksol process was purchased by another company, and the status of the equipment is unknown at this time (Jean Paquin, Sanexen Environmental Services, Inc., December 1996).

The remaining industrial unit of the company became known as Phillip Environmental, specializing in industrial cleaning (Jean Paquin, Sanexen Environmental Services, Inc., December 1996).

Technology Cost

The cost for the Extraksol technology is estimated to be $700 per ton ($771/tonne). This estimate is based on processing wet material, and it includes the cost of disposal and destruction of all residue, analyses associated with system operations, and mobilization (D14701D, p. 5.3).

Another source suggests that costs for the Extraksol technology would range between $200 and $700 per ton based on processing up to 6 tons per hour (personal communication: Jean Paquin, Sanexen Environmental Services, December 1996).

Information Source

D14701D, WASTECH, American Academy of Environmental Engineers, Chapter 5, 1995

T0304

F2 Associates, Inc.

Laser Ablation of Contaminants from Concrete and Metal Surfaces

Abstract

F2 Associates, Inc., has developed a decontamination and decommissioning (D & D) technology that uses short pulses of laser energy to remove paint and coatings contaminated with radionuclides or polychlorinated biphenyls (PCBs) from concrete and metal surfaces. The laser removes the coatings through ablation, which is the process of heating a substance so rapidly it is converted directly into the vapor phase. Hydrocarbon-based coatings are destroyed, and the targeted contamination can then be recovered using a vacuum filtration system. The ablation process reduces coating volume, which in turn reduces the amount of material requiring secondary treatment or disposal. Because laser ablation does not damage the underlying surfaces, it allows for the potential recycle and reuse of cleaned I-beams and other building materials.

Technology development is supported by the U.S. Department of Energy (DOE). The technology has been evaluated in bench-scale tests and is not currently commercially available.

According to DOE researchers, laser ablation has the following advantages:

- Reduces waste volumes (up to 75% for hydrocarbon-based coatings).
- Removes contaminants without damaging underlying materials.
- Removes contaminants from porous surfaces.
- Effectively captures removed contamination, reducing potential worker exposure.
- Allows for manual or fully automated operation.

The technology has not been applied to full-scale D & D projects, so complete operational parameters are not known.

Technology Cost

In 1998, U.S. Department of Energy (DOE) researchers estimated that using the F2 Associates, Inc., laser ablation process would cost \$9.92/ft^2 for a mobile robotic unit, and \$6.77/ft^2 if a hand-held unit was used. This estimate was for the D & D of paint 1 mil thick (D189031, p. vii). This compared favorably with conventional D & D technologies. Details of this estimate are summarized in Table 1.

Because laser ablation does not damage the underlying surfaces, it allows for the potential recycle and reuse of cleaned I-beams and other building materials. The ability to recycle building materials would greatly impact the ability to recover material costs of the D & D process. An undamaged steel I-beam that has been successfully decontaminated can be sold by the DOE for 27 cents per pound. If the I-beam is damaged during D & D, it is sold as scrap for only 3 cents per pound (D19764C, p. 1).

Another cost impact of laser ablation is that the technology reduces the volume of contaminated material requiring secondary treatment or disposal. According to the vendor, the removal and storage of contaminated waste costs the DOE \$330/ft^2, which is one-third the cost of the entire cleanup. The vendor says that a \$100 million D & D project using conventional coatings removal technologies would be reduced in cost to \$80 million if laser ablation technology was used (D19764C, p. 2).

Information Sources

D19764C, Texas Engineering Extension Service, 1999

D189031, Federal Energy Technology Center, 1998

TABLE 1 Comparison of Decontamination and Decommissioning Technologies

Technology	Cleaning Depth	Cleaning Rate (ft^2/hr)^2	Operating Costs (\$/ft^2)	Primary Waste Disposal Costs[a] (\$/ft^2)	Secondary Waste Disposal Costs[a] (\$/ft^2)	Total Cost (\$/ft^2)
Laser ablation (mobile robot)	15 mil (0.015 inches)	37.3	9.83	0	0.09	9.92
Laser ablation (hand-held unit)	15 mil (0.015 inches)	37.3	6.68	0	0.09	6.77
Sand blasting	0.125 inch	47	5.00–10.00	3.43	9.90	18.33–19.33
Steel grit blasting	0.125 inch	11.6	5.52	3.43	0.56	9.51
Soft media blasting	0.125 inch	80	10.00–11.00	3.43	0.82	14.25–15.25
Mechanical scabbling	0.125 inch	300	2.18	3.43	0.09	5.70

Source: Adapted from D189031.

[a]Based on a disposal cost of \$330/ft^3.

T0305

Ferguson International, Inc.

Petro-Belt and Dyna-Belt Hydrocarbon Skimmers

Abstract

The Petro-Belt and Dyna-Belt hydrocarbon skimmers are designed to remove floating hydrocarbons from sources where the liquid surface can be accessed, including from groundwater monitoring or extraction wells and industrial applications. Recovered hydrocarbons are scraped from the belt surface and routed directly to a 55-gal drum for storage.

The skimmers can be installed in groundwater monitoring or extraction wells with diameters of 2 inches or more, such as those found at gasoline service stations and other underground fuel storage locations, and can remove gasoline, diesel, fuel-oil, or other light non-aqueous-phase (LNAPL) hydrocarbons from the water's surface. Special belts are available for high-temperature or caustic applications. The units are portable and mount atop a 55-gal drum.

The Petro-Belt and Dyna-Belt families of hydrocarbon skimmers are currently commercially available from Ferguson International, Inc.

Technology Cost

The purchase prices of Petro-Belt and Dyna-Belt hydrocarbon skimmers are shown in Table 1. The minimum equipment required includes a skimmer, a belt, and a drum. For well applications in groundwater, the endurathane belt is to be used. This information is from a 1997 vendor brochure.

TABLE 1 Ferguson Industries Price List for Petro-Belt and Dyna-Belt Hydrocarbon Skimmers

Item	Description	Price
Petro-Belt PB-8	Hydrocarbon skimmer, drum or tank mount with lower pulley (no belt)	$2750.00
Petro-Belt PB-10	Hydrocarbon skimmer, vault- or pipe-mount, with lower pulley (no belt)	$2750.00
Endurathane belts	0.75- to 2-inch width, 10- to 20-ft reach	$148.50–$324.00
Petro-Cart	Utility cart	$858.00
Dyna-Belt D6-4	Oil skimmer for 4-inch-wide belt, with lower pulley (no belt)	$695.00
Dyna-Belt D6-8	Oil skimmer for 8-inch-wide belt, with lower pulley (no belt)	$742.00
Dyna-Belt D6-12	Oil skimmer for 12-inch-wide belt, with lower pulley (no belt)	$795.00
Polypropylene belts	4- to 12-inch widths, 63- to 123-inch actual lengths	$75.00–$220.00
Nitrile belts	4- to 12-inch widths, 75- to 123-inch actual widths	$66.00–$132.00
Nylon belts	4- to 8-inch widths, 63- to 99-inch actual lengths	$130.00–$210.00

Several other accessories are also available from the vendor.

Source: From D178523, pp. 9–12.

Information Source

D178523, Dynamic Process Industries, 1997

T0306

Ferro Corporation

Waste Vitrification through Electric Melting

Abstract
Waste vitrification through electric melting is an ex situ technology that uses electric resistance heating to treat contaminated soils. Vitrification involves the melting and subsequent refreezing of soil to create a glasslike solid in which inorganic contaminants are trapped and thereby isolated from the environment. The high temperatures that melt the soil also destroy organic contaminants within it.

Contaminated soils, sludges, and sediments are converted into oxide glasses, chemically rendering them nontoxic and suitable for landfilling as nonhazardous materials.

Although vitrification of soils is a well-documented remediation technique, research into this particular technology ceased at an early stage, and little information is available about it. This technology is not commercially available.

Technology Cost
There is no information available on the costs associated with this technology.

T0307

Filter Flow Technology, Inc.

Colloid-Polishing Filter Method

Abstract
Filter Flow Technology, Inc. (FFT), has developed the colloid-polishing filter method (CPFM) to remove ionic, colloidal, and complexed radionuclides and heavy metals from water. The technology uses an inorganic, insoluble, oxide-based compound [Filter Flow (FF) 1000] to remove radionuclide and heavy-metal pollutants from wastewater by a combination of sorption, chemical complexing, and filtration. The FF 1000 is contained within filter packs in a filter press unit. After use, the filter packs are dewatered with compressed air, forming a spent filter cake. The technology has been applied to groundwater treatment in both in situ and ex situ applications. The technology has been commercially available since the mid-1990s, with a total of 15 commercial projects planned or underway in 1994.

The vendor claims the following advantages of CPFM:

- Reduced capital costs through higher throughput and simpler and cheaper equipment
- Reduced operations and maintenance costs through reliability and simplicity of system
- Reduced quantity of solids for disposal generated due to the small-volume and potentially regenerable filter bed
- Improved removal efficiencies for multivalent, chelated, or complexed metals and radionuclides

In general, the CPFM technology is designed to remove trace to moderate levels [less than 1000 parts per million (ppm)] of nontritium radionuclides and heavy-metal pollutants present

in water. CPFM will not remove tritium. High organic compound concentrations may limiting process efficiency by interfering with the chemical and physical reactions occurring between the filter and the targeted pollutants.

Technology Cost

In a 1995 U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Demonstration Program Innovative Technology Evaluation Report, the costs of CPFM technology were estimated to range from \$2 to \$7 per 1000 gal of waste treated. Treatment costs depend on the contaminated groundwater characteristics and the duration of the remedial action (D10957J, p. iv). A summary of this analysis is given in Table 1.

The evaluation sited a number of factors that could affect process costs for groundwater treatment, including flow rate, type and concentration of contaminants, groundwater chemistry, physical site conditions, site location, availability of utilities, and treatment goals. Assumptions made for the cost estimate include any suspended solids are removed prior to CPFM treatment, the influent has an optimum pH of 8 to 9, and the ambient temperature of the influent is between 20 and 35°C. It was assumed that the system would be operational on an automated, continuous-flow mode, 7 days per week, 24 hours per day. This would lead to approximately 52.4 million gallons of water being treated in a 1-year period (D10957J, p. 22).

It is specified that the water to be treated contains 5000 ppm radionuclides, and the treatment goal is to reduce the wastewater to 2000 ppm. Water will be treated at a rate of 100 gal/min. All assumptions of the estimate are specified on pages 22–27 of D10957J.

Information Source

D10957J, U.S. EPA, 1995

TABLE 1 Costs (in Dollars) Associated with Colloid-Polishing Filter Method Treatment of Radionuclide-Contaminated Groundwater[a]

	Scheduled Treatment Time		
Cost Categories	1 year	5 years	10 years
Fixed Costs			
Site preparation	\$15,000	\$15,000	\$15,000
Permitting and regulatory	\$5,000	\$5,000	\$5,000
Capital equipment	\$291,500	\$291,500	\$291,500
Startup	\$1,000	\$1,000	\$1,000
Demobilization	\$20,000	\$20,000	\$20,000
Variable costs			
Labor	\$28,000	\$60,000	\$100,000
Consumables and supplies	\$11,900	\$52,100	\$102,500
Utilities	\$800	\$3,800	\$7,600
Effluent treatment and disposal	\$0	\$0	\$0
Residual and waste shipping and handling	\$24,700	\$123,500	\$247,000
Analytical services	\$24,000	\$120,000	\$240,000
Maintenance and modifications	\$5,000	\$25,000	\$75,000
Total fixed costs	\$292,500	\$292,500	\$292,500
Total variable costs	\$94,400	\$384,400	\$772,100
Total fixed + variable costs	\$386,900	\$676,900	\$1,064,600
Total cost per gallon treated	\$0.007	\$0.002	\$0.002

Source: Adapted from D10957J.

[a] Costs are based on September 1993 dollars and rounded to the nearest \$100.

T0308

First Environment, Inc.

FE ACTIVE

Abstract

The FE ACTIVE™ system is an in situ treatment technology that is used to remove volatile organic compounds (VOCs) from sands by aggressive cleaning and treatment by injection and vapor extraction. The technology combines pneumatic fracturing, dewatering, air injection, and vapor extraction. The FE ACTIVE system has the advantage of increasing water and air withdrawal from fractures in the saturated and unsaturated zones, thereby increasing the VOC removal rate.

According to the vendor, the FE ACTIVE system is not applicable to nonvolatiles, inorganic or radioactive wastes in groundwater or soil. Contaminants recovered by the FE ACTIVE system will require additional treatment or disposal.

Development of the FE ACTIVE system began in 1990 and was completed in 1992. This technology is currently commercially available.

Technology Cost

The estimated price for the FE ACTIVE system is \$10 to \$100/yd^3 of waste material. Mobilization, demobilization, and pilot testing of the system will cost approximately \$10,000 per site. These estimates do not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals. The cost of well installation is not included in these estimates. If wells are not present at the site, they must be installed at an additional cost.

Factors that have a significant effect on unit price include the following:

- Quantity of waste
- Initial contaminant concentration
- Target contaminant concentration
- Depth of contamination
- Depth to groundwater
- Characteristics of soil
- Labor rates
- Utility/fuel rates (D10102G, p. 14)

The vendor supplied an unspecified case study that compared the costs of an existing pump-and-treat system with a pump-and-treat system that had been retrofitted to accommodate an FE ACTIVE. The projected life-cycle cost (adjusted for an inflation rate of 4% and a rate of interest of 5%) of the existing pump-and-treat system was calculated to be \$3,930,000 (1996 dollars). The life-cycle cost (adjusted for a 4% inflation rate and a 5% interest rate) of the FE ACTIVE retrofit system was calculated at \$945,000 (1996 dollars). Both estimates included capital costs, operation and maintenance expenses, and the cost of groundwater monitoring. Similarly, had the FE ACTIVE system been installed initially, its life-cycle cost would be \$1,630,000 (1996 dollars).

According to the vendor, capital costs for the FE ACTIVE system and the pump-and-treat system are essentially the same. Although at this site, the FE ACTIVE system was retrofitted to the existing pump-and-treat system, capital costs of the FE ACTIVE system where no system exists are still only slightly higher than those of a pump-and-treat system. While annual costs are slightly higher using the FE ACTIVE system, its removal efficiencies result in a life-cycle cost 2 to 3 times lower than that of a pump-and-treat system (D11400R).

Information Sources

D10102G, VISITT Version 4.0, 1995
D11400R, http://www.gvi.net/soils/March96/vacuum.html, 1996

T0309

Fixed-Bed Soil Biofilters — General

Abstract

Biofiltration is the removal and oxidation of volatile organic compounds (VOC) from contaminated air by fixed beds of compost, soil, or peat. Biofiltration involves microbial populations immobilized on suitable support media to degrade or transform contaminants using biofilms.

Soil biofilters are relatively large compared to filters using other media since soil pores are smaller and compounds have low permeability in soil. Soil biofilters also have limited depths due to problems associated with maintaining humidity in soil and minimizing pressure drop. Furthermore, soil sorption capacity is limited and residual contaminants are vented immediately to the atmosphere.

Peat/compost biofilters use low-cost media but suffer from several problems, including: (1) susceptibility to channeling and maldistribution of the airstream, leading to uneven growth, (2) irreversible loss of bioactivity when moisture content decreases below a critical value, thereby requiring effective control of bed moisture content, (3) low degradation capacity, limiting biofilter applicability to low [<100 parts per million by volume (ppmv)] VOC concentration, (4) inadequate pH control in the bed by solid buffers that have limited neutralization capacity, and (5) eventual media replacement when the gas pressure drop reaches unacceptable limits due to biomass growth.

The major disadvantage of pelletized packed-bed biofilters is that they require periodic media cleaning to manage biomass growth.

Technology Cost

Estimated costs for this technology are \$8 (1991 dollars) per 10^6 ft^3 of air (D14012V, p. 37).

Information Source

D14012V, Bohn, 1992

T0310

Fluidized-Bed Thermal Oxidation — General

Abstract

Fluidized-bed combustion is a process in which fuel or waste is burned in a turbulent bed of heated particles, normally sand, which is suspended (fluidized) by combustion air. A fluidized bed is a bed of granular particles through which a flow of gas passes upwards. The particles are suspended in the upwardly flowing stream and have the appearance of a boiling liquid.

This technology is commercially available from several vendors.

The material fed into a fluid-bed incinerator must be in such a form that it can be fluidized — that is, it will be suspended in the rising airstream. Large or bulky solids will sink to the bottom of the bed, smolder, and interfere with the fluidization process. Large is a relative term and maximum permissible size will depend on specific gravity, fluidizing velocity, and other design parameters.

Fluid beds cannot be operated at temperatures above the melting point of the constituents in the bed.

Technology Cost

Fluidized beds have a lower capital cost than rotary types of incinerators and are more expensive than liquid injection incinerators. Operating costs of fluidized beds are comparable to those for rotary technologies, with power costs fractionally higher due to the fluidizing air fan. Maintenance costs are lower than those for rotary technologies and comparable to those for liquid injection systems. This is due primarily to longer refractory lives; fluidized beds, having no moving parts within the combustion zone, minimize refractory wear and mechanical fatigue (D161217, p. 8.39).

Capital cost for treating tar pond sludge at the rate of 31,000 tons/hr at a project in Sydney, Nova Scotia, was $16.25 million (1990 Canadian dollars) (D13916M, p. 173).

Information Sources

D161217, Rasmussen et al., 1989
D13916M, Boraston, 1990

T0311

FOREMOST Solutions, Inc.

BioLuxes and BioNet

Abstract

BioLuxing™ is a technique for enhancing in situ bioremediation in tight, low-porosity soils using hydraulic fracturing and/or jet-assisted injection techniques. A porous, inoculated substance is injected into a roughly horizontal fracture, or BioLux™, which functions as an in situ bioreactor. A BioNet™ is a series of BioLuxes forming a net-shaped pattern. When a BioNet is formed, biosurfactants may be used to reduce the surface tension of the contaminants, causing them to move downward into the BioLux. BioLuxes and BioNets can be applied only to biodegradable contaminants such as volatile and semivolatile organic compounds (VOCs and SVOCs).

The system has been demonstrated in full-scale commercial cleanups of contaminated soil and groundwater. It is currently commercially available.

According to the vendor, the benefits of BioLuxing include the following:

- Works in low porosity soils.
- Eliminates future contamination liability.
- Operates in active or passive modes and can be left in place after remediation is complete.
- Minimizes site disruption.
- Offers a low-cost remediation alternative.

Some zones may be resistant to fracturing because of cementation or mineralization; however, chemicals of concern may not be concentrated in these zones due to the likelihood of decreased porosity.

Technology Cost

Costs extrapolated from a U.S. Environmental Protection Agency (EPA) demonstration of BioLuxes in Denver, Colorado, have been reported as $28/yd^3 for sites with 3500 and 4000 yd^3 of contaminated soil. These costs exclude expenses associated with performance verification sampling and report preparation. The cost per installed fracture was $2300 (D17169R). According to the vendor, the design and construction at the site cost approximately $40,000, and monitoring costs were estimated to be $10,000 (D21474E, p. 7).

The vendor states that the system designed to treat fine-grained alluvial soil beneath an abandoned service station in Continental Divide, New Mexico, cost $141,000 for design and installation (D213332, Appendix, p. 41). The vendor also released cost data for a gasoline station in Lakewood, Colorado. A permeable treatment barrier was installed at the site in 12 days using hydraulic fracturing methods. After 14 months of operation, the system reduced benzene, toluene, ethylbenzene, and xylene (BTEX) concentrations up to 94%. The project was designed and installed for $160,000 (D213332, Appendix p. 93).

At the Mustang-Shadow Mountain Gas Station, in Grand Lake, Colorado, FOREMOST installed 3 BioNets containing 3 BioLuxes to remediate soils and groundwater contaminated with BTEX. The design and installation of this system cost $130,000 (D213332, Appendix p. 80).

Another source estimates the cost of using two BioNets with four fractures each as ranging from $60,000 to $70,000, while the cost of four BioNets with four fractures each ranged from $80,000 to $90,000. These costs equate to $10 to $20 per ton for remediation of contaminated soil at a typical site (D16920U).

According to the vendor, the cost of installing 88 BioLuxes in 22 BioNets at a manufacturing site in South Carolina was approximately $550,000. The BioLuxes were 30 to 50 ft in diameter and up to 1 inch thick. The system was installed 6 to 33 ft below ground surface (bgs). The vendor claims that project costs are less than half of the costs associated with using an iron boundary barrier (D22740H, p. 2).

Information Sources

D17169R, Stavnes et al., 1996
D16920U, FOREMOST Solutions, undated
D21474E, FOREMOST Solutions, Inc., undated
D213332, Roote, 2000
D22740H, FOREMOST Solutions, Inc., undated

T0312

FOREMOST Solutions, Inc.

IronNet™ and Iron Curtain™

Abstract

The IronNet™ and Iron Curtain™ are in situ treatment systems for dehalogenating chlorinated organic compounds in saturated soil and groundwater. Both systems degrade contaminants as groundwater flows through emplaced walls of zero-valent iron granules. The IronNet takes advantage of vertical groundwater flow and can create vertical flow if necessary using a novel in situ pump-and-treat mechanism. The Iron Curtain is a passive system that uses natural horizontal gradients to promote flow of groundwater through the zero-valent iron granules.

The IronNet is a permeable horizontal layer of zero-valent iron granules that is constructed in the saturated zone using hydraulic fracturing and jet-assisted injection techniques. The system can be used in or under the contamination source area where there is vertical movement of the contaminants, or where in situ pumping and cycling of groundwater can produce vertical movement of contaminants through the zero-valent iron granule filled fractures.

The Iron Curtain is a permeable vertical wall of zero-valent iron granules constructed in the saturated zone using jet-assisted injection techniques. The system can be used in or downgradient

of the contamination source area where there is horizontal movement of the contaminants, or where pumping and cycling of groundwater can produce horizontal movement of contaminants through the permeable zero-valent iron wall.

The vendor claims that these systems may be used in soils with a wide range of porosity values and can be installed at depths from 2 to 100 m below ground surface. The IronNet and Iron Curtain are only able to treat contaminants in the saturated zone. The Iron Curtain requires that there is a natural groundwater gradient and that groundwater flows horizontally at the site. Both technologies are currently commercially available from FOREMOST Solutions, Inc.

Technology Cost

In 1988, FOREMOST Solutions installed a pilot-scale permeable reactive treatment (PeRT) wall at Maxwell Air Force Base in Montgomery, Alabama. The project was designed and installed for $210,000 including the supplies and down-hole materials. Field installation was completed in 14 days (D213332, Appendix p. 74).

An Iron Curtain was installed at Cape Canaveral Air Station in 1997. The wall was installed in 8 days by jetted beam and continuous jet grouting techniques. According to the vendor, approximately 120 tons of zero-valent iron filing slurry were injected at a cost of $190,000. Total project cost for design, oversight, and installation was $250,000 (D21474E, p. 6).

Information Sources

D19355Z, Meiggs, 1999

D19354Y, Remediation Technologies Development Forum, 1998

D21474E, FOREMOST, Solutions, Inc., vendor web page

T0313

Forrester Environmental Services, Inc.

Heavy-Metal Stabilization

Abstract

Forrester Environmental Services, Inc., has developed a group of technologies for the stabilization of wastes containing heavy metals, such as lead, cadmium, arsenic, mercury, copper, zinc, and antimony. These technologies have been used in both industrial pollution prevention and remediation applications. One version of the technology involves the use of water-soluble phosphates and various complexing agents to produce a less soluble lead waste. This process results in a leach-resistant lead product.

Forrester Environmental Services, Inc.'s heavy-metal stabilization technologies have been issued several U.S. patents and are commercially available in the United States and Japan. The vendor claims these technologies have been permitted by the U.S. Environmental Protection Agency (EPA) and have been used at resource conservation and recovery act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites in several states. In addition, these technologies have been implemented at U.S. Department of Defense (DOD) facilities.

According to the vendor, Forrester Environmental Services, Inc.'s heavy-metal stabilization technologies have the following advantages:

- RCRA reporting, permitting, and fees are not required.
- Technologies are proven processes.
- Processes have low costs.

- Processes result in less than 1% increase in waste weight.
- Chemicals involved in processes are managed by Forrester Environmental Services, Inc.

Although the Forrester technologies may prevent the leaching of heavy-metal contaminants, they do not act to remove or destroy these contaminants.

Technology Cost
According to the vendor, the capital costs for installing Forrester's heavy-metal stabilization technologies at a fixed facility are between $0 and $7500, with operating costs of $5 to $10 per ton of waste. In addition, the vendor claims these technologies are $200 per ton less expensive than costs associated with RCRA Subtitle C landfill disposal. Costs for remedial applications of the Forrester heavy-metal stabilization technologies range from $10 to $25 per ton (D222220, pp. 1, 9).

Information Source

D222220, Forrester Environmental Services, Inc., undated

T0314

Foster Wheeler Development Corporation

Supercritical Water Oxidation

Abstract
Foster Wheeler Development Corporation (FWDC) has designed a transportable transpiring wall supercritical water oxidation (SCWO) reactor to treat hazardous wastes. As water is subjected to temperatures and pressures above its critical point (374.2°C, 22.1 MPa), it exhibits properties that differ from both liquid water and steam. At the critical point, the liquid and vapor phases of water have the same density. When the critical point is exceeded, hydrogen bonding between water molecules is essentially stopped. Some organic compounds that are normally insoluble in liquid water become completely soluble (miscible in all proportions) in supercritical water. Some water-soluble inorganic compounds, such as salts, become insoluble in supercritical water.

Under joint sponsorship by the U. S. Army Research, Development and Engineering Center (ARDEC) and the U. S. Department of Energy (DOE), a bench-scale transpiring wall reactor was developed by Sandia National Laboratories, FWDC, and GenCorp Aerojet. The reactor, which uses SCWO, was designed to treat military and other liquid wastes. A commercial application of the technology is in use to destroy munitions, colored smokes, and dyes. SWCO may also provide a viable alternative to incineration for the destruction of chemical weapons.

Problems common to SCWO technologies include reactor vessel corrosion, stress-cracking, and salt plugging. Low-organic-content waste streams may be more efficiently processed using other oxidation techniques or biological methods. Pretreatment is often necessary to obtain the proper percentage of organics in the waste feed and to render solids into a form that can be pumped. For some waste streams, solids handling may pose difficulties.

Technology Cost
Based on results of a study conducted by ARDEC, LaJeunesse et al. estimated the equipment cost of a pilot-scale SCWO research facility to be $615,000. They stated that construction and installation costs would increase the total cost by a factor of 2 or more. These 1994 estimates were based on the performance of a bench-scale Sandia unit with an average flow rate of 1.0 to 1.5 g/sec. For this study, the following assumptions were used:

- Daily throughput of 1000 gal
- Waste loading of 5% by weight
- Flow rate of 50 gal/hr
- System pressure of 4000 pounds per square inch (psi)
- Residence time of 15 sec at 550°C
- Reactor material consisting of Inconel 625
- Excess oxygen capacity of 100%
- Vendor quotes inflated by 20% (D120821, p. 22)

For the pilot plant, 39% of the equipment costs were for the reactor. Equipment costs are typically one-third to one-half of total construction costs. The proposed facility would require approximately 3350 kWh of energy. At 4 cents/kWh, daily electrical costs would be $134 per day (D120821).

According to a 1997 Environment Australia source, the general costs for SCWO technologies are $120 (U.S. dollars) to $140 per dry ton. These costs assume "some pretreatment and certain operating conditions" (D22124Z, pp. 22, 32).

Information Sources

D120821, LaJeunesse et al., 1994
D22124Z, Costner et al., 1998

T0315

Foster-Miller

Robotics

Abstract

Foster-Miller has developed robotics technologies with applications to environmental remediation. These robots include FERRET, a materials handling robot; Mini-Mucker, a remotely operated dump truck; Lemming, a robot designed for the retrieval of unexploded ordnance; and TALON, used for explosives detection and ordnance removal. Foster-Miller can also custom-design robots for specialized tasks. Foster-Miller's robotics technologies are commercially available.

According to the vendor, the TALON robot has the following advantages:

- It's "quick-release cargo bay" can carry different types of sensor equipment.
- It can be used in adverse weather conditions and at night.
- It can be used underwater.
- It can climb stairs and maneuver 45° grades.
- It can fit into the trunk of a compact-sized car for easy transport.

Technology Cost

No available information.

T0316

Freeze Crystallization — General

Abstract
Freeze crystallization is a technology that can be used to purify aqueous waste streams and concentrate liquid waste by the freezing and subsequent melting of the liquid. The terms freeze crystallization and freeze concentration are often used interchangeably.

Freeze concentration processes are based on the difference in component concentrations between solid and liquid phases that are in equilibrium. Most minerals and many organics grow less soluble in water as the temperature decreases. When an aqueous solution is cooled, ice usually crystallizes as a pure material, and dissolved components in the aqueous waste stream are concentrated in the remaining brine, thereby reducing the volume of waste.

This technology is different from other separation technologies in that it removes the water from the waste, rather than the waste from the water. Freeze crystallization can purify a waste stream in one step that might otherwise require several conventional processes working in series.

This technology can treat both acidic and basic solutions. It has the ability to remove organics, inorganics, radionuclides, and heavy metals from contaminated aqueous streams and is capable of treating process wastes and mixed wastes as well.

Technology Cost
In 1989, one vendor claimed that this technology would incur processing costs of \$0.03, \$0.09, and \$0.15 per gallon of waste treated, for 40-, 10-, and 5-gal/min systems, respectively (D130927, p. 2).

According to this same vendor, it is not economically feasible to treat wastes containing heavy metals with freezing technologies unless they are at levels between 1000 and 10,000 mg/liter. Aqueous streams containing organics must have contaminant levels over 3 to 7% by weight before it becomes feasible to treat them (D130927, p. 7). This vendor further states that freeze separation technologies become more economically competitive as the concentration of the waste stream increases (D130927, p. 7).

Information Source

D130927, Heist et al., 1989

T0317

freezeWALL, Inc.

freezeWALL Process

Abstract
The principle behind the freezeWALL process is to use refrigeration to convert in situ soil pore water into ice. The ice then acts as a bonding agent to fuse together particles of soil or blocks of rock, thereby increasing the strength of the mass and making it impervious. According to the vendor, the technology may be applied to soil ranging from clay to boulders and in pervious or fissured rock.

Ground freezing can provide an absolute water cutoff and can be installed in difficult ground conditions such as fills, boulders, and broken fractured rock, where other methods such as steel sheet piling, slurry walls, or jet grouting cannot practically be emplaced. The freezeWALL process has been used for varied applications including structural support and groundwater exclusion during tunnel digging operations and groundwater exclusion during remediation activities.

The technology has been used in a demonstration and a remedial program for the U.S. Department of Energy and also at several commercial sites. The freezeWALL technology is currently commercially available from freezeWALL, Inc., a division of Moretrench American Corporation.

According to the vendor, rapidly moving groundwater may be a concern when applying the freezeWALL process. All information provided herein has been provided by the vendor and has not been independently verified.

Technology Cost

According to the vendor, ground freezing applications are most cost effective when the freezing installation performs more than one function at once, such as when it is used simultaneously for support of excavation and groundwater. At one site, a main reason that ground freezing was selected for use was the very high permeability of soils, which would have made traditional pump-and-treat methods prohibitively costly (D19592A, pp. 8, 10).

At a site in New Iberia, Louisiana, freezeWALL installed a ground freezing system 240 ft below ground surface, intended to freeze an area of 3600 ft^2. This system used a trailer-mounted ammonia refrigeration plant and 58 freeze pipes located 6 ft apart. The duration of freezing is to last 35 months, and the contract amount was $6 million (D19593B, p. 2).

At a site in Brooklyn, New York, the ground was frozen for structural support and groundwater control. The frozen area was a 50-ft diameter circle at a depth of 145 ft. Forty-two freeze pipes were installed 3.6 ft apart, and the duration of freezing was 6 months. This project had a contract amount of $1 million (D19593B, p. 3).

A coffercell was frozen at the U.S. Department of Energy's (DOE's) Oak Ridge, Tennessee, facility to simulate containment of a leaking underground tank. The area of freezing is 1500 ft^2, to a depth of 30 ft. Forty-one freeze pipes were used, and placed 8 ft apart. The duration of the freeze was 6 months, and the project had a contract amount of $266,400 (D19593B, p. 4).

Other freezeWALL projects are similar in nature and had costs between $400,000 and $10 million depending on the size and complexity of the task (D19593B).

Information Sources

D19592A, Donohoe and Baker, 1999

D19593B, Moretrench American Corporation, 1998

T0318

FRX, Inc.

Hydraulic Fracturing

Abstract

FRX Inc., offers hydraulic fracturing technology to improve permeability and promote remediation in soils contaminated with organic compounds. The technique was first used to improve well yields in the petroleum industry. Hydraulic fracturing forms an integrated network of sand-filled fractures in contaminated clays, glacial tills, and other fine-grained or low-permeability sediments. These fractures increase well recovery rates, enhance site permeability, and reduce the time required for remediation. Hydraulic fracturing can be used in conjunction with treatment technologies such as soil vapor extraction, in situ bioremediation, pump-and-treat systems, free-product recovery for non-aqueous-phase liquids (NAPLs), or in situ vitrification. The technology has been used in full-scale site remediation activities and is commercially available.

The U.S. Department of Energy (DOE) found the following advantages for hydraulic fracturing technology:

- Enhances the performance of remediation technologies in low-permeability strata.
- Promotes better extraction of contaminants from or delivery of materials to the subsurface.
- Does not add significant up-front costs to overall remediation system.

Hydraulic fracturing technology does not remediate wastes and must be used in conjunction with a treatment technology. The maximum effective depth that can be achieved by hydraulic fracturing is dependent on the fracturing fluid viscosity; the pressure applied; the stiffness of the ground; and, in an indirect way, formation permeability. Pockets of low permeability may remain in the subsurface after the application of hydraulic fracturing. Hydraulic fracturing is ineffective in normally consolidated clays where the horizontal stress is less than the vertical stress. Hydraulic fracturing may cause ground heave, so monitoring is required when hydraulic fracturing is used near structures. The final location of the fractures is uncontrollable. Fractures may open new pathways for the unwanted spread of contaminants.

Technology Cost

During the 1993 evaluation of hydraulic fracturing technology performed by the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration program, it was estimated that the capital cost of hydraulic fracturing equipment was approximately $92,900. The cost of renting the equipment was approximately $1000 per day. Rental, operating, and monitoring costs for creating a fracture range from $950 to $1425 and depend on site-specific conditions. Typically 2 to 3 fractures are created per well, and 4 to 6 fractures can be created in a day. The cost of creating the fracture is not materially affected by the depth of the fracture for depths ranging from 5 to 40 ft below ground surface and is unaffected by the type of soil encountered. A summary of the cost estimates for hydraulic fracturing is included in Table 1.

TABLE 1 Estimated Costs Associated with Hydraulic Fracturing (in 1993 Dollars)[a]

Cost Category	Daily Cost (in dollars)
Site preparation	1000
Permitting and regulatory	5000
Capital equipment rental[b]	1000
Startup	0
Labor	2000
Supply and consumables	1000
Utilities	0
Effluent treatment and disposal	0
Residual waste shipping and handling	0
Analytical and monitoring	700
Maintenance and modifications	0
Demobilization	400
Total one-time costs (permitting and demobilization)	5400
Total daily costs	5700
Estimated cost per fracture (4 to 6 fractures per day)	950–1,425

Source: Adapted from D10054P.

[a] Assumptions include a site in the Midwest, suitable roads to the site, and that boreholes have already been drilled.

[b] Capital equipment rentals include equipment trailer, slurry mixer and pump, mixing pumps, tanks, hoses, fracturing lance, wellhead assembly, notching pump and accessories, uplift survey equipment, scale, and miscellaneous tools and hardware.

The cost to design and install a remediation system using hydraulic fracturing at a gasoline station in Lakewood, Colorado, was $160,000. The system included a PeRT barrier system, 7 Bio-Nets, and 31 BioLuxes. Bio-Nets and BioLuxes offered by Foremost Solutions, Inc., and discussed in RIMS2000 Technology Summary Number T0311 (D213332, p. A-93).

At an abandoned gasoline station in Continental Divide, New Mexico, Bio-Net technology was installed using hydraulic fracturing. The system was designed and installed for $141,000 (D213332, p. 29).

One conclusion from the SITE evaluation was that the cost of the technology is small compared to the benefits of enhanced remediation and the reduced number of wells needed to complete the remediation (D10054P, p. iv). In addition, the DOE concluded that hydraulic fractioning decreased the time required to cleanup a site due to more efficient contaminant removal. As a result, the maintenance and operating costs over the life cycle of the project also decreased (D183771, section 5 p. 2).

Information Sources

D10054P, U.S. EPA, 1993

D183771, U.S. DOE, 1998

D213332, Ground-Water Remediation Technologies Analysis Center, 2000

T0319

FTC Acquisition Corporation

DirCon Freeze Crystallization Process

Abstract

The DirCon™ freeze crystallization process is a technology that can be used to purify aqueous waste streams and concentrate liquid waste by the freezing and subsequent melting of the liquid. This technology is a type of direct-contact secondary-refrigerant freeze crystallization and operates on the principle that when water freezes, the crystal structure that forms naturally exudes contaminants from its matrix. The terms *freeze crystallization* and *freeze concentration* are often used interchangeably.

Freeze crystallization processes are based on the difference in component concentrations between solid and liquid phases that are in equilibrium. As an aqueous solution is cooled, ice usually crystallizes as a pure material, and dissolved components in the aqueous waste stream are concentrated in the remaining brine, thereby reducing the volume of waste.

This technology is different from other separation technologies in that it removes the water from the waste, rather than the waste from the water. Freeze crystallization can purify a waste stream in one step that otherwise requires several conventional processes working in series.

This technology can remove both organics, inorganics, radionuclides, and heavy metals from contaminated aqueous streams and is capable of treating process wastes and mixed wastes as well.

RIMS was unable to contact the vendor.

Technology Cost

The vendor claimed in 1989 that processing costs for this technology would be $0.03, $0.09, and $0.15 per gallon of waste treated, for 40-, 10-, and 5-gal/min systems, respectively (D130927, p. 2).

It is not economically feasible to treat wastes containing heavy metals with freezing technologies, unless they are at levels between 1000 and 10,000 mg/liter. Aqueous streams containing organics must have contaminant levels over 3 to 7% by weight before it becomes feasible to treat them (D130927, p. 7).

Preliminary chemical modeling by the developer found that “tank wastes” from fuel processing operations at U.S. nuclear weapons plants could be volume reduced by over 75%, at a cost of “cents per gallon.” These wastes are made up mostly of sodium nitrate in either a high pH or a 2 molar nitric acid solution. Radionuclides in these wastes only make up a few grams per liter, and current plans call for vitrification of these wastes (D130916, p. 10).

Information Sources

D130916, Heist and Hunt, 1994

D130927, Heist et al., 1989

D14490L, Westinghouse Hanford Company, 1993

T0320

Funkerburk & Associates

Solidification Process

Abstract

The HAZCON solidification process is an ex situ technology for the immobilization of metals and inorganic hazardous wastes in wet or dry soil and sludges. The technology is a cement-based process in which the contaminated material is mixed with pozzolanic materials such as Portland cement, a patented additive called Chloranan, and water. The process is capable of treating solids, sludges, semisolids, or liquids. The mixture hardens into a cohesive mass that immobilizes heavy metals.

Although the vendor claims that the Chloranan makes it possible to fixate wastes contaminated with high concentrations of organic compounds, results have varied. As a result, applications for immobilizing organic contaminants may need to be determined on a case-by-case basis.

The unique characteristic of the HAZCON process is the use of the proprietary ingredient Chloranan. The wastes most effectively solidified by the process are aqueous solutions, suspensions, or solids containing appreciable amounts of heavy metals and inorganic salts. The claimed characteristic of the Chloranan to inhibit the effects of organics on the crystallization of the cement is unique to the HAZCON process.

Treated soils undergo a volumetric increase of approximately 120%. Thus, the total treated waste may not be able to be placed back into the original excavation. The cost for removal to a landfill or other area could be substantial. Organic contaminants, including volatiles and base/neutral extractables are not immobilized to any significant extent. The vendor is no longer in business, and it is not known if the technology is currently commercially available.

Technology Cost

According to the vendor, the normal cost range for treatment of 1 yd^3 of waste varies from $15.00 to $120.00 ($12 to $96 per ton). Capital costs range from $75,000 to $250,000 depending on the output capacity of the blending equipment (D12909J, p. 32).

Economic analysis of costs based on pilot-scale demonstration results gave an estimated cost of $98 to $206 per ton of waste treated. 85 to 90% of these costs are for raw materials (cement and Chloranan) and labor. The lowest value ($98 per ton) is based upon the vendor’s expectation of reducing chemical consumption by 33%, attaining an on-stream factor of 90%, and using a new 2300-lb/min batch processing unit. These costs do not include profits of the contractors involved or permitting or environmental monitoring, and assume that operations are 7 days/week, 24 hr/day (D12909J, pp. 20–21).

Information Source

D12909J, EPA, May 1989

T0321

Fungi Perfecti

Mycova Mycoremediation and Mycofiltration

Abstract
Mycova^{SM} mycoremediation and mycofiltration are ex situ treatment technologies that use mushrooms to destroy total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAHs), and pathogens in contaminated soil, wood debris, wastewater, and surface water. The mushrooms are specially selected, cultured, screened, and preconditioned to treat a specific site's target contaminants. The mushrooms may be added directly to contaminated soil or used as a filter in wastewater and surface water applications.

Fungi Perfecti and the Battelle Marine Sciences Laboratory (Battelle) spent 4 years developing the Mycova mycoremediation technology. The technology has been tested during bench-scale evaluations and pilot-scale field demonstrations. According to the developers, the technology will require more research before it can be deployed on a commercial scale.

According to the developer, some advantages of the Mycova mycoremediation process are that it:

- Is faster than bioremediation applications.
- Minimizes maintenance requirements.
- Facilitates habitat restoration by attracting wildlife.

All information is from the developer and has not been independently verified.

Technology Cost
The vendor estimated that the costs of a commercial Mycova application would be less than $50/yd^3 of contaminated soil. This estimate included the costs of bulk fungal spawn on sawdust for inoculation, shade cloth covering, transportation, labor, and equipment for the application (D20841D, pp. 67, 68).

Information Source

D20841D, Thomas et al., undated

T0322

G.E.M. Inc.

Treatment of Chromated Copper Arsenate (CCA) in Wood Products

Abstract
Chromated copper arsenate (CCA) is used as a wood preservative. According to the technology developer, CCA-treated wood products resist decay and deterioration and are immune to moisture

and water-induced degradation. Pit wastes and by-products from the process are also resistant to moisture and degradation, making it difficult to treat them for environmentally safe disposal.

The CCA technology uses sulfuric and nitric acid to oxidize pit waste contaminated with CCA or waste products generated by wood preserving plants. In the process, CCA is recovered for recycling and the remaining solids are decontaminated for disposal.

The CCA technology is a patented (U.S. Patent 05415847) process. Currently (April 1997) it is not commercially available.

Technology Cost

No available information.

T0323

G.E.M., Inc.

Chemical Treatment

Abstract

G.E.M., Inc.'s, chemical treatment technology is a closed system in which hydrocarbons in water, soil, and sludge undergo oxidation. The technology is suited to the destruction of polychlorinated biphenyls (PCBs), halogenated cycladines (such as aldrin, endrin, and dieldrin), polar hydrocarbons (such as phenol and toluene), pentachlorophenol, and possibly dioxins. The ex situ treatment allows for testing before release of the cleaned matrix for disposal. The technology is based upon reaction of either an acid or caustic, with either the pollutant or a mixture of the pollutant and aluminum oxide to chemically convert the hydrocarbons to carbon and nonhazardous aluminum compounds. Treatment of soil and sludge or adsorbent contaminated with wastewater takes place in a heated pressure chamber. Steam and other gases are vented to a separate chamber for further processing if necessary. Residual hazardous materials can be adsorbed by rehydratable alumina and retreated. The system is initially to be used as a batch digester and will later be a continuous digester similar to the type employed at paper mills. The technology is not commercially available and has only been used at bench scale thus far.

The technology is not applicable to metals or other inorganic materials. Pretreatment to reduce the quantity of inert material mixed with hazardous waste will reduce the cost of this technology. Excess water in solid wastes to be treated is undesirable.

Because this is a closed system, nothing is released to the atmosphere during operation, and retreatment can be easily accomplished as necessary.

Technology Cost

The estimated price range for the chemical treatment technology is from \$150 to \$500 per ton of waste treated (D10101F, p. 9).

Information Source

D10101F, VISITT 4.0, 1995

T0324

Gaia Resource, Inc.

Gaia-Net

Abstract

Gaia-net is a technology for the in situ bioremediation of groundwater. RIMS was unable to contact Gaia Resource, Inc. It is unknown whether or not it is still in business as no information could be found as to its whereabouts, and it follows that commercial availability is also an unknown. The technology has not been demonstrated. According to information submitted by the vendor to the Environmental Protection Agency's (EPA's) VISITT database, the technology has been used in petroleum and natural gas field production. The technology was listed in EPA's VISITT database in 1995 but was not listed in the 1996 version.

After hydrogeological, chemical, and biological analysis of the subsurface is complete and parameters are known, a network of plastic tubing is injected in the contaminated plume and microbes are injected to destroy the contaminants. An impermeable vertical barrier or lining is installed with a vibratory hammer and insertion plate to maintain hydrogeologic control. The technology is capable of reaching depths of up to 100 ft.

The technology relies heavily on groundwater modeling and an understanding of nuclear, chemical, and biological processes. Mathematical models are used to represent processes that involve biotransformation, subsurface reactions, or mineral dissolutions/precipitation reactions. They report that while these parameters are relatively well understood, fundamental gaps in knowledge still exist in describing the interactions that may occur among constituents.

All information was supplied by the vendor and could not be verified by an independent source.

Technology Cost
No available information.

T0325

Galson Remediation Corporation

APEG-PLUS Process

Abstract
The APEG-PLUS process is a technology for the ex situ treatment of chlorinated contaminants in a number of media. It is a form of alkaline dechlorination that uses an alkaline metal hydroxide with polyethylene glycol (APEG) as a reagent. It has been used to treat dioxin-contaminated solids and sludges.

There is little information available regarding this technology, and RIMS was unable to contact the vendor.

Technology Cost
For a full-scale application, the APEG process is estimated to cost between $200 and $500 per ton. This range does not include the costs associated with excavation, refilling, residue disposal, and analytical expenses. Other factors such as soil type and soil moisture can also affect treatment costs (D20225V, p. 4). One study indicated that costs averaged $24/gal of waste treated when using potassium polyethylene glycol as the process reagent (D205403, p. 4–25).

Information Sources

D20225V, Federal Remediation Technologies Roundtable, undated
D205403, U.S. EPA, 1997

T0326

General Atomics

Acoustic Barrier Particulate Separator

Abstract
The acoustic barrier particulate separator technology treats off-gases by means of an acoustic waveform directed against the gas flow, which causes particulates to move opposite the flow.

The particulates drift to the wall of the separator, where they aggregate with other particulates and precipitate into a collection hopper. The acoustic barrier particulate separator differs from other separators by combining both high-efficiency and high-temperature capabilities.

The acoustic barrier particulate separator has been tested at the pilot-scale level. Pilot-scale tests were impaired because of a design problem in the acoustic separator. Funding cuts have prevented construction and testing of a corrected design. This technology is not currently commercially available.

The process can agglomerate and remove particulates smaller than 1 μm only if a sufficient number of particulates are present to allow collisions between particulates in the acoustic field. Other potential disadvantages include the requirements for sound containment and the power requirement for operating the acoustic source.

Technology Cost

According to the vendor, the electricity cost for the pilot device [a 300 standard cubic feet per minute (scfm) unit] would be approximately $4 (1996 dollars) per hour. The cost to make the siren was approximately $23,000 (1996 dollars). This consists of $17,000 machining, $3000 materials, and $3000 assembly (D15199P, pp. 4, 23).

Information Source

D15199P, General Atomics, 1996

T0327

General Atomics

Circulating Bed Combustor

Abstract

The circulating bed combustor (CBC) is a fluidized-bed incinerator that uses high-velocity air to entrain circulating solids and create a highly turbulent combustion zone for the efficient destruction of toxic hydrocarbons. This technology can be applied to hazardous and nonhazardous materials in the form of organic solids, soils, liquids, sludges, and slurries. According to the vendor, the CBC is applicable for polychlorinated biphenyls (PCBs), dioxin, and other halogenated and nonhalogenated wastes such as pesticides, oily wastes, munitions, and chemical agents.

The CBC technology operates at relatively low temperatures [approximately 1600°F (870°C)], thus reducing operation costs. The high turbulence produces a uniform temperature and promotes the complete mixing of the waste material during combustion. The effective mixing and relatively low temperature also reduce emissions of carbon monoxide and nitrogen oxides.

This technology is currently owned by General Atomics and has been applied in U.S., German, and Canadian facilities. General Atomics is currently not pursuing the technology commercially in the United States; however, it maintains the technical and related capabilities.

Technology Cost

Costs range from $150 to $300 (1991 dollars) per ton ($165 to $330 per metric ton) of soil for quantities of 20,000 to 50,000 tons (18,000 to 45,000 metric tons) of soil and $350 to $400 (1991 dollars) per ton ($386 to $441 per metric ton) of soil for quantities of 10,000 to 15,000 tons (9100 to 14,000 metric tons) of soil. These prices are based on the quantity of material to be treated, moisture, and organic content of the contaminants. These prices are for incineration only and do not include excavation (D130676, p. 202).

Based on data from the Superfund Innovative Technology Evaluation (SITE) program demonstration, total demonstration project costs were calculated to be $813,505 (1992 dollars). The vendor calculated costs to prepare for and execute the treatability study at their pilot-scale facility. The Environmental Protection Agency (EPA) calculated the costs for waste preparation, transportation, sampling and analysis, waste disposal, and report preparation. These costs are based on the following factors:

- Permitting and regulatory costs
- Labor costs
- Supplies and consumables
- Residuals and waste shipping, handling, and transport costs
- Analytical costs
- Facility modification, repair, and replacement costs
- Site demobilization costs

Factors that are excluded from the demonstration project costs include the following:

- Site preparation costs
- Equipment costs

TABLE 1 Detailed Breakout of Demonstration Project Costs

Cost Category	Vendor Test Preparation Costs	Vendor Test Execution Costs	EPA Costs
Site preparation	N/A[a]	N/A	N/A
Permitting and regulatory			
APCD[b] fees	$40,345	—	N/A
Vendor labor	16,416	—	—
Equipment	N/A	N/A	N/A
Startup and fixed costs	N/A	N/A	N/A
Labor			
Contract labor	9,918	29,298	197,110
Vendor labor	6,000	36,416	—
Supplies and consumables[c]	—	13,430	70,700
Effluent treatment and disposal	N/A	N/A	N/A
Residuals and waste shipping, handling, and transport	NI[d]	NI	11,000
Analytical costs	NI	NI	324,190
Facility modification, feed and vent system modifications	12,538	—	17,000
Contract labor	4,150	—	—
Vendor labor	2,000	—	—
Site demobilization			
Supplies	—	2,594	N/A
Contract labor	—	8,400	—
Vendor Labor	—	12,000	—
Total	$91,367	$102,138	$620,000
Total Costs	$813,505		

Source: From D12907H, U.S. EPA, 1992.
[a] Not applicable.
[b] Air Pollution Control District.
[c] Limestone costs were $166 per ton ($183 per metric ton) of Pfizer limestone; $18.75 per ton ($20.67 per metric ton) (1986 quoted price) Colton limestone.
[d] Not included.

- Startup and fixed costs
- Effluent treatment and disposal costs.

These costs are not to be used to extrapolate to the potential on-site costs of a full-scale operation (D12907H, p. 51). Table 1 gives a detailed breakout of the demonstration project costs (D12907H, p. 52).

Information Sources

D130676, Diot and Young, 1991
D12907H, U.S. EPA, 1992

T0328

General Atomics

Cryofracture

Abstract

The cryofracture technology was developed to access the agent and explosive in chemical agent munitions for subsequent destruction. In this pretreatment technology, liquid nitrogen is used to cryocool munitions before fracturing them in a hydraulic press. All munition handling is performed by remotely controlled programmed robots. After fracturing (exposing the agent and explosive), the munitions can be dropped into a furnace or other treatment system where the chemical agent and explosive are destroyed. The method has also been used as a pretreatment, size reduction step for processing transuranic- (TRU-)contaminated waste in drums and boxes. General Atomics has been developing the process for over 15 years. All information is from the vendor and has not been independently verified.

Technology Cost

According to the vendor, a government-sponsored study concluded that cryofracture could reduce the cost of disposal of munitions when compared with processes that require disassembly of the munitions. The current U.S. demilitarization process uses a sensitive reverse-assembly process requiring custom-designed machinery to disassemble each type of weapon. The cryofracture process simply freezes and crushes the ammunitions (D15198O).

Information Source

D15198O, General Atomics, undated

T0329

General Atomics

Supercritical Water Oxidation

Abstract

General Atomics (GA) has developed supercritical water oxidation (SCWO) systems to treat organic wastes, sludges, chemical agents, and other hazardous materials. As water is subjected to temperatures and pressures above its critical point (374.2°C, 22.1 MPa), it exhibits

properties that differ from both liquid water and steam. At the critical point, the liquid and vapor phase of water have the same density. When this point is exceeded, hydrogen bonding between water molecules essentially stops. Some organic compounds that are normally insoluble in liquid water become completely soluble (miscible in all proportions) in supercritical water. Other water-soluble inorganic compounds, such as salts, become insoluble in supercritical water.

SCWO is commercially available through GA; however, no full-scale applications of GA's technology had been performed as of 2000. Three pilot-scale units are in operation: One tested at the Illinois Institute of Technology, one built for the U.S. Air Force, and one built for the U.S. Navy.

According to GA, the SCWO technology offers the following advantages:

- Is capable of high destruction and removal efficiencies (DREs).
- Produces small amounts of nitrogen oxides (NO_x) and sulfur oxides (SO_x).
- Produces no dioxins or furans.
- Is a contained process with no smokestack.
- Is easily permitted.
- Operates at relatively low temperatures.
- Is compact.
- Is competitively priced.

Problems common to SCWO technologies include reactor vessel corrosion, stress-cracking, salt plugging, and erosion of control valves. Waste streams with low organic content may be more efficiently processed using other oxidation techniques or biological methods. Pretreatment may be necessary to obtain the proper percentage of organics in the waste feed and to render solids into a form that can be pumped.

Technology Cost

In 1990, Thomason estimated the cost of operating an SCWO facility based on results of MODAR pilot-scale studies and plans for a commercial facility. The primary factors influencing costs of an SCWO unit were the treatment capacity of the facility and the organics concentration of the feed material. For a plant capable of processing 76 m^3/day, total costs were estimated at \$80 to \$130/m^3. This estimate is based on the treatment of wastes with an average heating value of 3500 to 4200 kilojoules per kilogram (kJ/kg) and an organic concentration of 10%. A system with a treatment capacity of 380 m^3/day is estimated to cost between \$26 and \$53/m^3. Costs for treating waste streams containing 1 to 2% organics, processed in the 380-m^3 facility, would be \$18 to \$40/m^3. Costs were also estimated for processing soils. To process 50 m^3/day of solids, costs were estimated to be \$200 to \$300/m^3. At a rate of 500 m^3/day, costs were estimated at \$80 to \$120/m^3 (D11985R, p. 41). In 1994, the cost of building a 20-liter/min SCWO system was approximately \$2,000,000 (D22698W, p. 2).

Based on a study conducted by the Assembled Chemical Weapons Assessment Program, capital costs for GA's SCWO technology were thought to be 5 to 10% less than costs for incineration. Because of the uncertainties associated with this estimate, researchers reported to Congress that capital costs for SCWO and incineration were nearly equal. Labor requirements were found to be similar for the two technologies, but insufficient data was available for an in-depth comparison (D22691P, p. 2–30).

According to a 1997 Environment Australia source, the general costs for SCWO technologies are \$120 (U.S. dollars) to \$140 per dry ton. These costs assume "some pretreatment and certain operating conditions" (D22124Z, pp. 22, 32).

Information Sources

D11985R, Thomason et al., 1990
D22124Z, Costner et al., 1998
D22691P, U.S. EPA, 2000
D22698W, NATO, 1994

T0330

General Electric Company

Thermal Heating Blanket

Abstract
The thermal heating blanket is an in situ thermal desorption system that combines thermal desorption and vacuum extraction to separate organic compounds from in-place contaminated soil. It can be used on soils in situ or ex situ.

This technology was patented by General Electric Company on October 7, 1997. The technology has been demonstrated at field pilot scale and is commercially available.

The heating blanket assembly has four basic components: a surface heating element, a thermal insulating mat, a vacuum collection system, and a vapor barrier. The heating blanket unit is applied directly to the surface of the hydrocarbon-contaminated soil. The surface heater boils water at a given depth, above which the temperature increases approximately linearly to the surface temperature. The semivolatile contaminants are dissociated or desorbed from between the boiling water front and the surface. As the soil is heated, organic compounds and water vapor are desorbed and removed from the soil matrix. The vapor collection system purges volatile organic compounds (VOCs), water, and other gases from the soil pores and sweeps in air from surrounding soils to oxidize organics. Air pollution control equipment is used to treat the off-gas, as necessary, to satisfy air emissions requirements.

This technology can only be applied to sites where the water table is below the depth of the contamination.

Technology Cost
No available information.

T0331

Genesis Eco Systems, Inc.

Soil Treatment and Recycling

Abstract
The Genesis Eco Systems, Inc. (Genesis), soil treatment and recycling (STAR) technology is an ex situ soil washing process. This technology is also referred to as the SABRE-1 soil washing system. SABRE-1 is an acronym for Surfactant-Activated Bio-enhanced Remediation Equipment—Generation 1. This technology treats hydrocarbon-contaminated soil. The system breaks apart the soil and uses a combination of surfactant stripping and active bioremediation to degrade contaminants. The equipment removes contamination by using a proprietary surfactant blend.

Commercial availability of this technology is uncertain.

Process effectiveness is determined by bacterial proliferation and soil type. Extremes of temperature and pH, high clay content, and low soil nutrient values will slow the process.

Heavy molecular weight hydrocarbons such as grease may require preprocessing to achieve remediation goals. The system is not designed to handle tars or asphalts. Sticky clays or fines fractions exceeding 40% may reduce operating efficiencies.

Technology Cost

The cost for this technology is $25 to $40 (1995 dollars) per ton of material treated. This estimate does not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals.

Factors that have a significant effect on unit price include the following:

- Quantity of waste
- Characteristics of soil
- Site preparation
- Initial contaminant concentration
- Target contaminant concentration
- Amount of debris with waste
- Waste handling/preprocessing
- Characteristics of residual waste
- Labor rates (D100970, p. 17)

Information Source

D100970, VISITT Version 4.0, 1995

T0332

GeneSyst International, Inc.

Supercritical Gravity Pressure Vessel

Abstract

Supercritical water oxidation (SCWO) has been proven to destroy some forms of organic waste. The process operates at temperatures and pressures above the critical point of water (374.2°C, 22.1 MPa). A general discussion of SCWO is included in the RIMS library/database (T0756).

GeneSyst International, Inc., is developing supercritical gravity pressure vessel (SGPV) technology that will achieve supercritical conditions by allowing the wastes to descend through a column to a depth of approximately 12,800 ft. As they descend, the wastes are warmed by heat exchangers until temperatures in the supercritical range are approached. The pressure created by the water column is approximately 23 MPa. At the base of the reaction column, oxygen is injected. The subsequent reaction raises the temperature of the waste to about 399°C. The vendor claims that the technology will destroy organic wastes and oxidize metals to nonhazardous forms.

SGPV is an emerging technology. Design, operational, and performance issues remain currently untested. The vendor is currently planning a commercial facility.

The vendor claims the following advantages of SGPV technology:

- Allows for higher flow rates than other technologies, reducing operating costs.
- Can treat many different types of waste streams.
- Simplifies permitting as the only gas released is carbon dioxide, and the system has a secondary containment system in case of leaks.
- It is safer to operate, as the process reactions occur far underground, and process effluent is under far lower temperatures and pressures than surface SCWO systems.

Waste streams with a high chlorine content require dilution before processing to limit corrosion of the vessel. Due to the 10% by weight solids limitation, there is an inherent large dilution ratio required for solid materials. No SGPV facilities are recommended in salt domes or in areas where the vessel will cross a seismic fault line.

Technology Cost

In 1996, a cost estimate was prepared for the U.S. Department of Energy (DOE) for constructing SGPV systems to treat low-level mixed waste (mixed wastes are materials that contain both hazardous and radioactive components). This analysis estimated costs of SGPV systems capable of processing waste at rates of 240, 400, 480, and 600 gpm. For this analysis, it was assumed that the gravity vessel would be composed of a titanium with a 1% rubidium alloy content, grade 8 or grade 18. The cost per pound of the reactor material was estimated to be $21.50/lb (D17156M, pp. 14–17).

Processing rates varied for the units based on the diameter of the gravity vessel. In all cases the unit was to be installed to a depth of 12,800 ft (for the purposes of the cost estimate). It was assumed that the unit would be emplaced in Utah, under severe drilling conditions. Construction costs were assumed to include all costs of materials, construction, drilling, permitting, and materials handling. These costs are listed in Rappe, 1997, and are summarized in Table 1.

For this cost analysis, an estimate of site support facilities was also performed. These costs included monitoring and control offices, site enclosure, control and safety equipment, waste preparation, waste shipping and processing, employee facilities, foundations, and installation of utilities (D17156M, pp. 17–18). These costs are also summarized in Table 1.

According to this data, costs could be minimized by constructing a small number of large-capacity units. It was estimated that the annual cost of operating an SGPV unit was generally insensitive to the amount of waste the unit treated in a year. The total number of hours the unit was operable in a year was estimated at 4032 hr per year as a baseline case, but the vendor claims that the unit can be operated for approximately 7800 hr per year. The vendor states that the most effective system for treating the volume of mixed wastes stored in DOE facilities is the 400 gpm unit (D17156M, pp. 19–23).

The vendor states that in many cases it may not be necessary for the SGPV to operate under supercritical conditions. This may reduce processing costs. System setup and waste stream characteristics will have an impact on system costs (D17183P, p. 4).

Information Sources

D17156M, Rappe, 1997

D17183P, Genesyst, undated vendor literature

TABLE 1 Cost Estimate for Construction and Operation of SGPV System to Treat Low-Level Mixed Waste

Cost Item	240-gpm Unit	400-gpm Unit	480-gpm Unit	600-gpm Unit
Construction	$18,171,850	$20,460,720	$23,167,640	$24,015,680
Site support	$31,550,000	$31,700,000	$31,900,000	$32,100,000
Total capitalization	$49,721,850	$52,160,720	$55,067,640	$56,115,680
Treatment rate[a]	24	40	48	60
Cost ratio[b]	2.07	1.30	1.15	0.94
Annual operation	$16,000,000	$17,000,000	$18,000,000	$20,000,000

Source: Adapted from D17156M.

[a]Treatment rate is the amount of solid mixed waste treated per minute, assuming a dilution factor of 10:1.

[b]The cost ratio is the capital cost divided by the flow rate of mixed waste through the unit.

T0333

Geo-Cleanse International, Inc. (formerly known as Geo-Care, Inc.)

Geo-Cleanse Process

Abstract
The Geo-Cleanse® process is used for the in situ remediation of organic contaminants in soil and groundwater. The technology uses a proprietary, in situ chemical oxidation system that injects and disperses nonhazardous chemical compounds (commonly hydrogen peroxide) and reagents into subsurface environments to destroy organic contaminants. The vendor states that the reagents employed in the process degrade rapidly into water and oxygen at the end of the treatment process and are nonhazardous to the environment and to potable well systems.

The Geo-Cleanse process remediates soil and groundwater contaminated with organic compounds including fuel oils, gasoline, solvents, halogenated compounds, pesticides, polychlorinated biphenyls (PCBs), and other organic contaminants.

The Geo-Cleanse process is patented and has been used in full-scale site remediation. The technology is commercially available.

According to the vendor, the Geo-Cleanse process offers the following advantages:

- Process is cost-efficient.
- Process reduces cleanup time and requires minimal site disruption.
- Treatment can work in areas that are generally inaccessible to other methods.

The process has the following limitations:

- High concentrations of carbonate in the soil or hard water conditions at the site can increase treatment costs.
- High heat and pressures can be generated during treatment.
- The technology is less cost effective at sites with high contaminant concentrations.

Technology Cost
According to the vendor, the Geo-Cleanse process does not require capital investments, monthly operational fees, monthly maintenance fees, or local permits. The exclusion of these costs substantially reduces treatment costs (D12376C).

There is a substantial range of costs for Geo-Cleanse in situ chemical oxidation. Factors impacting project costs include the volume and distribution of contamination, the quantity and nature of the contaminant, and the hydraulic conductivity of the formation. These parameters effect the number of injectors needed, amount of hydrogen peroxide and other reagents required, and the time requirements for delivery of injections to the subsurface. Unit costs for large sites with high contamination levels have been reported to be less than $50/kg of contaminant oxidized. Conversely, small low-level contamination sites can be associated with costs over $100/kg of contaminant oxidized (D186612, p. 10).

In 1997, this technology was used in the field to treat dense non-aqueous-phase liquids (DNAPLs) at the U.S. Department of Energy's (DOE's) Savannah River Site near Aiken, South Carolina. The total cost of the demonstration was approximately $511,000 for treatment of 64,000 ft^3 of soil containing approximately 600 lb of DNAPL. Listed costs included approximately $60,000 for site preparation; $151,000 for pretest drilling and characterization; $184,000 for a technology test; $49,000 for posttest drilling and characterization; $7000 for demobilization; and $60,000 for documentation and project management (D18766A, p. 10).

During another field application in 1997, Geo-Cleanse was used to remove DNAPLs from over 43,125 yd^3 of contaminated soil at the DOD's Anniston Army Depot in Anniston, Alabama.

The soil contained 72,000 lb of volatile organic compounds (VOCs). The total cost to complete the project was estimated to be $5.7 million. According to project managers, approximately two-thirds of the funds were allocated for capital costs (including chemicals and the injection process) and one-third for monitoring and support (D18766A, p. 3).

In 1998 and 1999, the Geo-Cleanse process was used to treat 16,500 gal of groundwater contaminated with trichloroethene (TCE) at the DOD's Naval Air Station in Pensacola, Florida. According to the vendor, the total cost for the demonstration was $178,338. Approximately $97,018 of the total were capital expenses and the remaining $81,320 covered operation and maintenance costs. The costs associated with electrical power and water supply were not included in the final cost figure (D21045X, p. 127).

During phase I operations at the DOD's Submarine Base Kings Bay, Site 11 in Camden County, Georgia, Geo-Cleanse treated approximately 78,989 gal of groundwater contaminated with tetrachloroethene (PCE), TCE, dichloroethene (DCE), and vinyl chloride. The total proposed costs for phase I were $223,000, including costs for reagents, mobilization, on-site treatment time, injection and monitoring equipment, documentation, and injection construction oversight and materials (D21045X, p. 129).

At the DOD's Letterkenny Army Base in Letterkenny, Pennsylvania, the Geo-Cleanse process was used to treat vadose zone soils contaminated with chlorinated solvents and benzene, toluene, ethylbenzene, and xylenes (BTEX). The actual remediation costs were approximately $700,000 (D200964, pp. 9, 16, 17).

The unit cost of the technology during a pilot-scale demonstration at the DOD's Shaw Air Force Base in Sumter, South Carolina, was $8700/lb of VOCs removed. Based on this test, the estimated cost for a full-scale demonstration of 400-by-300-ft area was $2.5 million over 3 years (D200964, p. 17).

In June 2001, the Interstate Technology Regulatory Cooperation (ITRC) Work Group published technical and regulatory guidelines for in situ chemical oxidation of contaminated soil and groundwater. The guidance document contains information that can be used in preparing cost estimates for chemical oxidation technologies like the Geo-Cleanse system. For more information, please see D22442A, Appendix D.

Although many of the costs for chemical oxidation technologies will be site specific, chemical costs will generally average 15 to 30% of the total remediation costs. Factors that influence chemical costs will include the chemical oxygen demand (COD) of the contaminated media, pH, the size of the site, and initial contaminant concentrations (D22442A, pp. 19, D-1).

Information Sources

D12376C, Geo-Cleanse International, Inc. and GEO-CARE, Inc.

D186612, Bryant and Wilson, 1998

D18766A, U.S. EPA, 1998

D200964, Environmental Security Technology Certification Program, 1999

D21045X, Federal Remediation Technologies Roundtable, 2000

D22442A, Interstate Technology and Regulatory Cooperation Work Group, 2001

T0334

Geo-Con, Inc.

Shallow Soil Mixing/Thermally Enhanced Vapor Extraction

Abstract

Geo-Con, Inc., has developed a method to enhance removal of volatile organic compounds (VOCs) in clayey soil using a combination of shallow soil mixing, soil vapor extraction, and hot

air injection. It is applicable to any site with contaminants that volatilize easily. This technology has been applied at sites with trichloroethylene (TCE) and other VOCs to depths of over 6.7 m. The vendor states that the technology can treat soils to depths over 14.3 m.

This technology differs from other vacuum extraction technologies in that the mixing process exposes much more of the soil to the heated air, accelerating contaminant volatilization. The auger unit can also inject any liquid or gas to enhance the remediation process. Due to the in situ nature of the treatment, cost savings can be realized since dewatering and shoring practices associated with technologies requiring excavation are eliminated.

In 1993, Geo-Con, Inc., first used the shallow soil mixing/thermally enhanced vapor extraction (SSM/TEVE) technology at the Portsmouth Gaseous Diffusion Plant. It has since been used at several other sites to accelerate contaminant volatilization (D14483M, p. 2).

The SSM/TEVE system is best suited for removing VOCs, and has been shown to reduce the average soil concentration of VOCs by 90%. The shallow soil mixing technology is also used to mix various solidification/stabilization slurries into the soil for the treatment of inorganic contaminants (including radionuclides). (Refer to the Geo-Con in situ solidification/stabilization process).

The limiting factors for successful soil mixing treatment include the presence of boulders and subsurface utilities such as underground wires or piping. Depth to the water table may adversely impact the vapor extraction components effectiveness because vapor phase off-gas systems cannot process liquid streams. The vendor claims that depth to the water table may also influence lateral migration of processing gases.

Technology Cost

The approximate cost for shallow soil mixing/thermally enhanced vapor extraction technology range from \$60 to \$100/yd^3 of soils treated. Costs and applications of this technology are site specific. This cost may be reduced given the desired level of testing and quality assurance/quality control measures required (D13379J, p. 28).

At the U.S. Department of Energy's (DOE's) Portsmouth Gaseous Diffusion Plant in Ohio, treatment of 20,000 yd^3 of soil cost approximately \$3.5 million (D10096Z, p. 10).

Information Source

D13379J, Carey et al., 1995

T0335

Geo-Con, Inc.

Deep Soil Mixing Technology

Abstract

Geo-Con, Inc.'s deep soil mixing (DSM) technology is an in situ soil mixing technology. Using a multiple-auger setup with built-in injectors, the process can be used to treat or immobilize inorganic and some organic compounds in wet or dry soil. It is applicable to sediments, pond bottoms, and almost any soil. The technology has been field tested on soil containing polychlorinated biphenyls (PCBs), pentachlorophenol, refinery wastes, and chlorinated and nitrated hydrocarbons.

DSM technology has been combined with several other remediation methods, including ambient air stripping, heated air stripping, peroxide injection, in situ creation of impermeable barriers, permeable barrier creation for in situ treatment, and in situ stabilization and solidification of contaminants.

In April, 1988, DSM technology was demonstrated under the Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) program. Since that

time, the vendor claims the DSM process has been used over 50 times for in situ stabilization in the United States and has treated over 2 million cubic yards of contaminated soils and sludges. DSM is related to two other Geo-Con, Inc., technologies in the RIMS2000 library database, Shallow Soil Mixing Solidification/Stabilization Process (T0336) and Shallow Soil Mixing/Thermally Enhanced Vapor Extraction (T0334). All of these technologies are currently commercially available.

According to the vendor, soil mixing technologies have the following advantages:

- Cost less than competing technologies.
- Reduce exposure of wastes to the surface and contaminant off-gas generation.
- Allow for in situ treatment of soils, eliminating off-site disposal.

Limiting factors include difficulty in stabilizing contaminants at great depths, compromising the site for future usage and problems in dealing with soil containing large underground obstructions. The effects of weather may cause problems; freeze/dry weathering tests on the product have shown unsatisfactory weight loss results. Capping is often necessary.

Technology Cost

Process costs were $194/ton of contaminated soil for the one-auger system used during a 1988 EPA SITE demonstration at a Florida site. During the full-scale remediation of the site using a commercial four-auger unit, costs were $111/ton (D17048J, pp. 25–29). More recently, larger equipment has reduced process costs to as low as $15/ton plus the cost of chemical additives (D10710Y, p. 78). Geo-Con, Inc., reports more typical process costs of $40 to $50/yd^3 plus chemical costs (D12569J, p. 1).

In 1992, the vendor provided the U.S. Department of Energy (DOE) with cost estimates for the use of DSM technology with three treatment technologies: vapor extraction with hot air injection, jet mixing, and grout injection for solidification/stabilization. The estimate was based on the following assumptions: a treatment area of approximately 29,000 ft^2; contamination to a depth of 25 ft below ground surface (bgs), target contamination of volatile organic compounds (VOCs), with a target cleanup goal of 90% destruction/removal/stabilization for a total soil contamination of less than 1 mg/kg. Estimates varied from $45 to $170/yd^3 of soil treated (D21472C, p. 126). Details of the estimate are provided in Table 1.

In 1999, Andromalos et al., reported on a pilot-scale installation of a permeable barrier using DSM technology. Total installation costs were approximately $200,000. The cost of iron filings were $425 to $450 per ton (D19370Y, pp. 4–5).

Because of the potentially large amounts of reagents and additives that need to be transported to the site, transportation costs may limit economic feasibility if a source of chemicals is regionally unavailable (D12572E, p. 2).

TABLE 1 Vendor Cost Analysis of Deep Soil Mixing Combined with Treatment Technologies

	Production Schedule in Weeks			Unit Costs in \$/yd^3	
Technology	8-ft Columns	10-ft Columns	Mobilization Costs in $	8-ft Columns	10-ft Columns
Hot air injection	28.8	18.4	$250,000	$75	$60
In situ stabilization	14.4	9.2	$150,000	$55	$45
Jet mixing	55.8	55.8	$70,000	$170	$170

Source: Adapted from D21472C.

Information Sources

D17048J, U.S. Environmental Protection Agency, August, 1990

D12572E, U.S. DOE, web page, undated

D12569J, Geo-Con, Inc., vendor web page, 1996

D19370Y, Andromalos et al., 1999

D21472C, U.S. DOE, 1995

T0336

Geo-Con, Inc.

Shallow Soil Mixing

Abstract

Geo-Con, Inc., offers shallow soil mixing (SSM) technology to solidify and stabilize contaminants in situ. The shallow soil mixing technology has also been used for geotechnical stabilization of foundations in loose sands and as protection against liquifaction of soils during earthquakes.

Using a single-auger system with a built-in injector, SSM technology uses chemical reagents to produce a cementlike mass that immobilizes inorganic and some organic compounds. The technology can be applied to wet or dry soils. SSM has been applied to sites contaminated with volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals. The technology has been applied to full-scale cleanups and is commercially available.

According to the vendor, shallow soil mixing has the following advantages:

- Costs less than competing technologies.
- Reduces exposure of wastes to the surface and contaminant off-gas generation.
- Allows for in situ treatment of soils, eliminating off-site disposal.

Any buried debris can cause problems. Large rocks or debris can interrupt processing, leaving an area of untreated soil. The volume of soil increases during the mixing and injection process. The long-term effects of weathering on treated soils are uncertain.

Technology Cost

Process costs were $194 per ton of contaminated soil for the single-auger system used in the 1988 U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration of deep soil mixing technology (a related Geo-Con, Inc., product). More recently, larger equipment has reduced the process costs to as low as $15/ton plus the added costs of chemical reagents (D10710Y, p. 78). Geo-Con, Inc., reports that SSM technology costs generally range from $40 and $50/yd^3 plus reagent costs (D12569J, p. 1).

Due to the potentially large amounts of reagents that may need to be brought to the site, transportation costs may limit the economic feasibility if a source of reagents is not available in the nearby region (D12572E, p. 2).

Information Sources

D10710Y, Annual Status Report SITE Program, 1995

D12572E, Remediation Technologies Screening Matrix, Section 4.7

D12569J, Geo-Con web site: www.copa.geocon.htm, dwnld:10/3/96

T0337

Geokinetics International, Inc.

Pool Process Electrokinetic Remediation

Abstract

Pool Process™ electrokinetic remediation (Pool Process) is a patented, commercially available technology for the removal of heavy metals and other ionic contaminants. The technology uses a series of electrodes placed in contaminated media to recover ionic contaminants in situ or ex situ from soils, muds, groundwater, dredgings, and other materials. The Pool Process can also be used to enhance bioremediation of media contaminated with a combination of ionic and nonionic organic contaminants.

Geokinetics International, Inc., has developed other applications for this technology as well. It can be set up as an electrokinetic ring fence to recover ionic contamination from groundwater as it flows past the electrodes. It may also be used as a soil heating element in conjunction with soil vapor or groundwater extraction to remove organics from soil.

According to the Interstate Technology and Regulatory Cooperation Work Group and the Ground-Water Remediation Technologies Analysis Center, the Pool Process has the following advantages:

- May be able to treat soils not accessible for excavation.
- Applicable in soils with low permeability and high clay content.
- Desorbs and mobilizes contaminants.
- Treats inorganic and organic contaminants.
- Capable of remediating heavy-metal contamination in unsaturated soils.
- Is cost effective.

It may be difficult to estimate the time that will be required to remediate a site using the Pool Process. Heterogeneities or anomalies in the soil will reduce removal efficiencies. The electrokinetic remediation process is also limited by the pH of the soil, the solubility of the contaminant, the desorption of the contaminants from the soil matrix, the amount of moisture in the soil, contaminant and noncontaminant concentrations, and reduction–oxidation changes induced by the electrode reactors. In bioremedial applications, concentrations of contaminants may be too high for indigenous or transplanted microbial populations to initiate degradation. Additionally, the bioremediation of contaminants may produce by-products that are toxic to the microbial community thus ceasing biodegradation processes.

Technology Cost

In 1996, the typical cost of remediation using the Pool Process electrokinetic remediation technology was estimated to range from \$150 to \$250/yd^3. The vendor estimates the costs for small, rapid, turnkey remediation projects to range from \$120 to \$170/yd^3. According to the vendor, sites with more than 2000 yd^3 of contaminated material can be remediated at a process cost of \$20 to \$80/yd^3 (D13496N, p. 1; D13659O, p. 4; D20958P, p. 4).

The costs will vary based on the site's specific chemical and hydraulic properties. The initial and target contaminant concentrations, concentrations of nontarget ions, conductivity of the pore water, soil characteristics and moisture content, the quantity of waste, depth of contamination, residual waste handling and processing, site preparation requirements, and electricity and labor rates have a significant effect on the unit price (D19938G, pp. 16, 17).

To extract metals from soil using electrokinetic remediation may require 500 or more kilowatt hours of energy per cubic meter if the electrodes are spaced from 1 to 1.5 m apart. Direct costs

TABLE 1 Total Costs of Pool Process Electrokinetic Remediation Projects

Site	Year	Media Treated	Cost
Former Paint Factory, Groningen, The Netherlands	1987	400 yd^3 of clay contaminated with copper, lead, and zinc	\$120,000
Galvanizing Plant, Delft, The Netherlands	1988	300 yd^3 of clay contaminated with zinc and cadmium	\$160,000
Former Wood Treatment Facility, Loppersum, The Netherlands	1989	3000 yd^3 of clay contaminated with arsenic and copper	\$160,000
Gardens and Canals, Stadskanaal, The Netherlands	1990–1992	2500 yd^3 soil and sludge contaminated with cadmium	\$960,000
Dutch Air Force Base, Woensdrecht, The Netherlands	1992–1994	3400 yd^3 sludge contaminated with chromium, nickel, copper, zinc, lead, and cadmium	\$1,040,000

Source: From D20958P.

of energy, plus enhancements, could result in direct costs of \$50 or more per cubic meter (D17868B, p. 3).

Table 1 discussed the costs of specific pilot-scale demonstrations.

Information Sources

D13496N, SRI International, 1996

D13659O, Geokinetics, undated

D17868B, Federal Remediation Technologies Roundtable, undated

D178705, Geokinetics, undated

D19938G, Interstate Technology and Regulatory Cooperation Work Group, 1997

D20958P, Geokinetics International, Inc., 1997

T0338

Geo-Microbial Technologies, Inc.

Catalyst Cleanup

Abstract

This is an anaerobic biological technology to recover metals from contaminated catalysts. However, it can be applied to other solid or sludge support materials that have metal contamination.

Geo-Microbial Technologies, Inc., is not in the waste cleanup business. This technology was discovered during work Geo-Microbial was doing in the oil and gas industry, and, seeing its potential applications in treating drilling muds, the company is interested in possible licensing-type relationships with other businesses or individuals (personal communication: Dan Hitzman, President, Geo-Microbial Technologies). This technology has not been demonstrated beyond bench scale.

A typical process consists of a media containing spent-metal catalysts in the form of oily pellets. The waste is then injected with microorganisms and nutrients in a reactor. The

microorganisms leach the metal from the catalyst support material. The metals are then recovered for reuse.

All information was supplied by the vendor and could not be independently verified.

Technology Cost
No available information.

T0339

Geo-Microbial Technologies, Inc.

Enzymatic Treatment of Waste Drilling Muds

Abstract
This is an in situ bioremediation technology for treating waste drilling muds.

Geo-Microbial Technologies, Inc., is not in the waste cleanup business. This technology was discovered during work Geo-Microbial was doing in the oil and gas industry, and, seeing its potential applications in treating drilling muds, the company is interested in possible licensing-type relationships with other businesses or individuals (personal communication: Dan Hitzman, President, Geo-Microbial Technologies). This technology has not been demonstrated beyond bench scale.

This technology is for the cleanup of well site drilling mud pits. The volume of such wastes is reduced by separating the water and oil phases, and the spent drilling mud can be removed from the well. Mud is treated with enzymes specifically designed for the various components that are added to the mud to enhance its drilling capabilities. This enzymatic degradation is rapid and causes the breakdown of the mud characteristics. The technology and enzymes can be designed for individual mud systems or can be employed for general classes of mud.

All information was provided by the vendor and could not be independently verified.

Technology Cost
No available information.

T0340

Geo-Microbial Technologies, Inc.

Heteroatom Extraction Technology

Abstract
Geo-Microbial Technologies, Inc., is offering for license an extraction technology for the removal of compounds containing heteroatoms from oils and contaminated soils. A heteroatom is an atom other than carbon (e.g., nitrogen, sulfur, and metals) in the ring of an organic cyclic compound (i.e., a heterocyclic compound). The technology uses a combination of water and carbon dioxide operating under relatively low temperatures and pressures to separate the contaminated oil products without physical modification or destruction of the oil. The technology is not currently commercially available.

According to the vendor, the advantages of this technology are that it operates under moderate temperatures and pressures, the oil that is treated is purified without thermal or chemical alteration, and the system operates in a closed-loop mode with no waste streams being discharged.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0341

Geo-Microbial Technologies, Inc.

Hydrogen Sulfide Removal

Abstract
This is a bioremediation technology exclusively for the removal of hydrogen sulfide in situ and can be applied to soil or groundwater. The technology was discovered during work in the oil and gas industry. Seeing its potential applications in hydrogen sulfide remediation, Geo-Microbial Technologies, Inc., pursued it in a bench-scale experiment. Geo-Microbial Technologies, Inc., is not in the waste cleanup business but is interested in possible licensing-type relationships with other businesses or individuals.

The technology uses specific microorganisms, either introduced or indigenous, that consume hydrogen sulfide. The same organisms also consume nutrients required by other organisms that are producing the hydrogen sulfide, thereby eliminating the production of more hydrogen sulfide. Specific hydrogen sulfide consuming strains can be injected into the contaminated media, or stimulants, in the form of nutrients, can be injected to encourage the growth of microorganisms already present in the system.

This technology is targeted only for hydrogen sulfide. It requires anaerobic conditions, nutrients, and in the case of water applications, transportation media (water/brine).

Technology Cost
No capital costs would be required because the technology would operate under the same in situ conditions as those prevailing where hydrogen sulfide is generated. No further cost information is available (D10094X, p. 2).

Information Source

D10094X, VISITT 4.0

T0342

Geo-Microbial Technologies, Inc.

Metals Release and Removal from Wastes

Abstract
This is an ex situ anaerobic bioremediation technology for metal-contaminated soils, sludges, and sediments. While metals are the primary pollutant treated, the biological system also degrades and removes organics such as hydrocarbons.

Geo-Microbial Technologies, Inc., is not in the waste cleanup business. This technology was discovered during work Geo-Microbial was doing in the oil and gas industry, and, seeing its potential applications in treating drilling muds, the company is interested in possible licensing-type relationships with other businesses or individuals. This technology has not been demonstrated.

The system operates anaerobically and at near neutral pH, employing anaerobic *Thiobacillus* cultures in consortium with heterotrophic denitrifying cultures. The denitrifying population

releases the metals when soils containing the metals are flooded with the dilute nitrate solutions. These improved anaerobic leach solutions permeate the soils, allowing the metals to be solubilized into the leachate by the microbial consortium. The nitrate concentration is adjusted so that the effluent is free of nitrate; the nitrate concentration is monitored so that the process operation can be closely controlled. The solubilized metals in the leachate are recaptured by established processes, and the metal-free effluent is recycled within the process.

All information was provided by the vendor and could not be independently verified.

Technology Cost
No available information.

T0343

Georgia Institute of Technology Construction Research Center

In Situ Plasma Vitrification

Abstract
The Georgia Institute of Technology (Georgia Tech) Construction Research Center is currently researching in situ vitrification for the treatment and stabilization of hazardous, radioactive, and low-level mixed wastes. The wastes are treated by inserting a plasma torch into the bottom of a treatment borehole and melting the material around the torch. This produces a column of vitrified material as the torch is slowly raised to the ground surface. The plasma can create temperatures between 4000 and 7000°C, destroying organic wastes and melting inorganic wastes that solidify into a glassy, nonleachable final waste form. The technology is available for licensing and is still being researched at Georgia Tech. The technology is being applied to a commercial municipal waste facility in Bordeaux, France, but has not been applied commercially in the United States.

Researchers claim that in situ vitrification is:

- *Versatile*: remediates a variety of mixed wastes and operates under varying ground conditions and sediment types.
- *Safe*: operates with minimum exposure to buried contaminants, and works from the bottom of the site to the top, reducing the possibility of explosions, and ensuring that target depth is reached.
- *Effective*: produces a high rate of vitrification and remediation.
- *Efficient*: operates with a high degree of thermal coupling of the soil, and offers a significant cost reduction compared to other in situ vitrification techniques.

High groundwater content increases processing costs, and high groundwater flow rates may prevent the technology from operating efficiently.

Technology Cost
In a 1994 evaluation of in situ plasma vitrification, the cost of remediating a one-acre area contaminated to a depth of 10 ft using a 5-MW mobile plasma system was estimated at $130 per ton (D11871I, p. 716). A summary of the cost estimate is given in Table 1. According to researchers, treating radioactive wastes would cost from $250 to $400 per ton, and treating municipal waste contamination would cost approximately $50 per ton. Simple, nonwaste treatment soil stabilization operations would cost between $30 and $80 per ton (D15319F).

Information Sources

D11871I, Circeo et al., 1994

D15319F, Nemeth, web page, 1996

TABLE 1 Projected Remediation Costs for a Hazardous/Toxic Waste Contaminated Site Using In Situ Plasma Vitrification

Cost Category	Explanation	Cost (dollars)
Capital cost	10-year project life, 6-month project	0.5 million
Drilling cost	2 ft of overburden, 400 boreholes	0.5 million
Electricity cost	500 kW/ton of waste treated	0.6 million
Labor cost	5-person shift, 2 shifts per day	0.9 million
Maintenance cost	$100/hr of operation	0.3 million
Total cost	Sum of above costs	2.8 million
Cost per ton of waste treated		130

Source: Adapted from D11871I.

T0344

Geosafe Corporation

In Situ Vitrification

Abstract
Geosafe Corporation has developed in situ vitrification (ISV), a commercially available technology for the treatment of soils, sludges, sediments, and mine tailings contaminated with organic and inorganic compounds. Geosafe Corporation is now using the name GeoMelt™ to describe its family of vitrification technologies.

The ISV process uses electricity to heat and melt soil and other earthen materials contaminated with organic, inorganic, and radioactive compounds. Organic compounds undergo pyrolysis (thermal decomposition in the absence of oxygen). The pyrolyzed compounds then migrate to the surface zone, where they are collected and oxidized in a collection hood. Inorganic and radioactive components are incorporated as oxides into a leach-resistant vitrified product.

According to the vendor, ISV technology has the following advantages:

- Waste can be treated in place or staged in a cell for ex situ treatment.
- Organic, inorganic, and radioactive wastes are processed simultaneously with significant volume reduction in treated waste.
- Technology has high tolerance for debris.
- Inorganic wastes are permanently immobilized.
- Technology is mobile, easy to set up.

Sites having high groundwater flow rates may hinder ISV processing. in situ processing of soils near buildings or property lines may require modifications to limit thermal gradients. Treated soils may take over a year to cool. Organics content of the soil is limited to 7 to 10% by weight. Flammable liquid or water vapor trapped under a melt could cause venting through the melt rather than around it, possibly allowing fugitive emission releases.

The hood fitted above the site to trap off-gases generated by ISV processing is capable of accepting variations in ground levels of about 0.15 m. In testing at Oak Ridge National Laboratory, steam buildup underneath the molten mass caused the expulsion of vapor that released shards of radioactive glass and lifted the gas collection hood. The expulsion was caused by trapped water beneath the melt in a low-permeability rock formation. No airborne contamination was detected from this event.

Technology Cost

According to the vendor, costs for using ISV to treat hazardous waste can range from $400 to $500 per ton. The vendor also states that the off-gas treatment components for sites contaminated with radioactive wastes can cost between $600 and $1000 per ton (D205334, p. 6). Factors that impact ISV costs include the amount of site preparation required, properties of the media to be treated (density, water content, etc.), volume of material to be processed, depth of processing, unit price of electricity, and season of the year. Costs can vary by $55 to $77 per metric ton between treating dry soil and treating fully saturated soil. In such cases, predrying the soil may become cost effective (D136016, pp. 853–854). Expenses can also be higher in rural areas without an adequate power source. Running power lines to a site can add $25,000 per mile to project costs (D205334, p. 6).

Based on data collected during the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program demonstration in 1995, a cost estimate was prepared for ISV treatment of soil. The cost for treatment when the soil is staged into nine cells is approximately $1300/yd^3 for 5-ft-deep cells, $770/yd^3 for 15-ft cells, and $660/yd^3 for 20-ft-deep cells. These estimates are for the contaminated soil only and include all mobilization/demobilization costs. Cost estimates do not include vendor profit (D123320, p. 41). For sites backfilled, total volume of material treated will be higher than the amount of contaminated soil treated (D123320, p. 7). These cost estimates are summarized in Table 1.

In 1994, average costs for treatability studies were estimated by the vendor to be $40,000 to $80,000, of which $15,000 to $50,000 is for analytical chemistry services. Equipment fees and mobilization costs were estimated at $200,000 to $300,000 combined (D10857G, p. 4–36). Also in 1994, costs for ISV processing were estimated to average $350 to $450 per ton for hazardous wastes, and $400 to $550 per ton for radioactive wastes, plus the mobilization/demobilization cost (D13589R, p. 2).

TABLE 1 Summary of Economic Analysis Estimates in Cost/yd^{3a}

Cost Category	Case 1: 970 yd^3 (\$/yd^3)	Case 2: 3200 yd^3 (\$/yd^3)	Case 3: 4400 yd^3 (\$/yd^3)
Site preparation	51	18	13
Permitting	27	9	7
Equipment	190	98	83
Startup and fixed	260	130	110
Labor	250	150	130
Materials and Supplies	80	61	52
Utilities	180	170	160
Effluent treatment	0	0	0
Residuals and wastes; shipping and handling	34	26	23
Analytical services	52	19	14
Facility modifications and maintenance	170	86	59
Demobilization	37	13	9
Total cost/yd^3	1300	770	660
Total cost/ton	740	430	370

Source: Adapted from U.S EPA, 1995 (D123320, p. 34).

[a] Estimates are based on a wet soil density of 1.8 tons/yd^3 (2.1 tons/m^3) based on SITE demonstration results. Costs based on contaminated soil treated. All costs are rounded to two significant figures, based on the sum of the individual costs before rounding.

In 1998, Sigmon and Skorska noted that most of the cost data for vitrification technologies are based on pilot-scale operations. Such data are suspect because they are based more on extrapolation than experience. The estimates are also difficult to compare because the estimates they are based upon may vary widely (D18248T, p. 55).

Based on demonstration results at the Idaho National Engineering and Environmental Laboratory, the costs of using ISV to treat underground storage tanks (USTs) at the facility would be $4.3 million. This estimate "does not include costs associated with identification, management, and control of the ROD [Record of Decision]" (D20675H, p. 14). The U.S. Department of Energy (DOE) also notes that using Geosafe's ISV technology at their facilities should be less expensive than baseline excavate and treat technologies (D20116R, p. 1).

Information Sources

D10857G, U.S. Department of Defense, 1994
D123320, U.S. EPA, 1995
D13589R, Ames Laboratory, 1994
D136016, Smith, 1994
D18248T, Sigmon and Skorska, 1998
D20116R, U.S. DOE, 1999
D205334, U.S. DOD, 1998

T0345

Geotech Development Corporation

Cold Top Ex Situ Vitrification Process

Abstract
Geotech Development Corporation offers a proprietary Cold Top ex situ vitrification process for the treatment of contaminated soil. The system melts the soil using an electric resistance furnace that can operate at temperatures of up to 5200°F. The vendor claims that wastes are transformed into an essentially monolithic, vitrified mass. The process is termed "cold top" vitrification because soil is added to the top of the melt to act as an insulator and to minimize the loss of volatile metals into the off-gas treatment system. The technology has been evaluated in a pilot-scale facility and is commercially available.

The vendor claims Cold Top vitrification offers the following advantages:

- Can accomplish volume reductions as high as 10:1.
- The vitrified final waste form is a nonleachable, nonbiodegradable solid that does not require disposal as hazardous waste.
- The vitrified solid can potentially be transformed into products of economic value.

This process is not efficient in treating wastes with high water content (greater than 10%). Organic compounds should be removed through light incineration before processing. Some wastes will require the addition of carbon and/or sand to produce a glasslike final waste form. Wastes with large amounts of metallic components may require treatment by magnetic separators to prevent the formation of a secondary high-iron ferro furnace bottom material during treatment.

Technology Cost
The vendor states that costs for Cold Top vitrification would generally range from $50 to $147 per ton. The primary factor determining costs is power requirements, which will vary with the material treated. The vendor states that dumping the waste in a hazardous waste landfill

would often require a $500 per ton tipping fee, indicating that the technology would be a viable alternative to landfilling hazardous wastes (D17167P, p. 9).

The vendor prepared economic projections for the costs of a facility treating municipal solid waste ash at varying input rates. For these facilities, power usage would be the greatest component of treatment costs, followed by labor costs. Treatment costs varied from $48 to $65 per ton. Details of these estimates are given in D17167P, pp. 18–21.

The vendor also prepared economic projections for facilities treating asbestos ash residues at varying input rates. These facilities would require higher labor costs, with power requirements being the second highest component of treatment costs. Treatment costs varied from $130 to $175 per ton. Details of these estimates are given in D17167P, pp. 22–24.

According to Robert T. Mueller of the State of New Jersey Department of Environmental Protection (NJDEP), demonstrations conducted by the vendor have supported the premise that the cost to vitrify waste into nonleachable materials is substantially lower than the excavation and relocation of these materials to regulated landfills as a means of permanent disposal (D17164M, p. 1).

Information Sources

D17164M, Mueller, 1997

D17167P, Geotech Development Corporation, undated

T0346

Geotech Environmental Equipment, Inc.

Scavenger Recovery Systems

Abstract

Geotech Environmental Equipment, Inc., offers a series of Scavenger™ product recovery systems that use membrane and sensor technology to separate product from subsurface waters in situ so that an oil/water separator at the surface will not be needed. The systems can recover hydrocarbons floating on groundwater and dense non-aqueous-phase liquids (DNAPLs) that have sunk below the groundwater surface. These systems can be used in open lagoons, trenches, settling ponds, large-diameter or small-diameter wells, and shallow or deep wells. The Filter Scavenger™ uses a unique oleophilic/hydrophobic membrane to separate water from product. Filter Bucket™ is a passive system that uses the same membrane technology but does not require electricity. It is used to retrieve small quantities of hydrocarbons. The Probe Scavenger™ uses oil/water level sensors to provide high volume recovery of water-free hydrocarbons. The Filter Bucket and Filter Scavenger systems will work with alkanes, alkenes, aromatic hydrocarbons, alcohols with four or more carbons, esters with five or more carbon atoms, and mono-alkyl halides. This technology is currently commercially available.

For material to be recovered by the Filter Scavenger and Filter Bucket, it must float on water (i.e., must have a specific gravity of less than 1.0) and have a kinematic viscosity of less than 45 centistokes (cSt) for use with the "light" oil filter cartridge and 150 cSt for use with the "heavy" oil filter cartridge. Short-chain alcohols, carbon disulfide, chloroform, carbon tetrachloride, and other dense solvents that are heavier than water can only be recovered using the Probe Scavenger. Solvents that are lighter than water can be recovered with the filters. If the water is very acidic or basic (generally with a pH less than 5 or greater than 9), a pH Scavenger™ may be necessary. The Aromatic Filter Scavenger™ must be used to recover materials containing aromatic hydrocarbons.

Technology Cost

No available information.

T0347

Gerardo International, Inc.

Magnetic Resonance X-ray (MRX) Technology

Abstract
Gerardo International, Inc., claims to have developed magnetic resonance X-ray (MRX) technology for the treatment of hazardous wastes. MRX is based on a tunable soft-spectrum X-ray laser source both for contaminant detection by light-scattering spectroscopy and for molecular detection. The molecular spectroscopic information is used to tune the X-ray source to the correct frequency for optimal waste destruction. Gerardo International claims the technology has applications to organic, inorganic, and radioactive contaminants and may have applications to heavy metals. According to the vendor, the technology is currently proprietary, and publication of the process is expected in approximately 2006. A related application of MRX technology will be developed in Malaysia for a commercial desalinization facility.

All information included in this summary was supplied by the vendor and has not been independently verified. The technology is predicated upon the existence of a tunable X-ray laser. The current state-of-the-art in this area suggests that, at best, the availability of the technology is many years in the future.

Technology Cost
No available information.

T0348

GHEA Associates

GHEA Associates Process

Abstract
The GHEA Associates (GHEA) process is an ex situ soil washing technology that uses selected surfactants (detergent-like chemicals) in a water solution to extract both inorganic and organic contaminants from excavated soil. The surfactants interact with both oil-soluble organics and water-soluble metal ions. The resulting mixture is purified by extracting the surfactant–contaminant complex. The complex is separated into a recoverable surfactant fraction and a contaminant fraction.

The GHEA process is applicable to soil, sludges, sediments, slurries, groundwater, surface water, end-of-pipe industrial effluents, and in situ soil flushing. The technology can treat both organics and heavy metals, nonvolatile and volatile organic compounds, and highly toxic refractory compounds. The technology is not commercially available.

The advantages of the GHEA process include the following:

- Is applicable to complex contaminant mixtures in a single integrated process.
- Capable of processing highly toxic compounds because the process does not rely on biological processes.
- Purifies both solid and aqueous media.
- Uses surfactants that are nontoxic and nonflammable.

High levels of organic matter in the soil can interfere with the removal of polychlorinated biphenyls (PCBs).

TABLE 1 Engineering/Cost Studies for the Use of GHEA Associates Soil Washing Technology

	Case 1 2.5 tons	Case 2 12.5 tons
Capital cost (U.S.)	\$3.2 million	\$8.5 million
Tons per year	20,000	100,000
Operating costs/ton	\$88–\$111	\$57–\$80

Source: Adapted from D13377H.

Technology Cost

The treatment costs for the GHEA Associates process depend on the soil matrix, properties, chemical composition of the contaminants, and other site-specific factors. The commercial-scale, integrated process, consists of the extraction and wash liquor purification steps. The estimated costs for the process range from \$50 to \$80 per ton of soil treated. Other separation processes have estimated treatment costs ranging from \$90 to \$200 per ton (D13377H, pp. 793, 799).

In 1996, the vendor-published engineering/cost studies for two potential treatment systems. One of the systems treated 20,000 tons of soil per year, and the other system treated 100,000 tons of soil per year. Both estimates were based on continuous, 3-shift, 7-day/week operation. These estimates are summarized in Table 1 (D13377H, p. 793).

Information Sources

D106503, SITE Technology Profiles, October 1995

D13377H, GHEA Associates

T0349

Global Remediation Technologies, Inc.

Pressurized Fluidized Bioreactor (PFBR)

Abstract

Global Remediation Technologies, Inc., has designed and is in the process of patenting a pressurized fluidized bioreactor (PFBR) for enhancing biosparging and bioventing.

According to the vendor, the PFBR has recently been introduced to the commercial market through a press release.

All information is from the vendor and has not been independently verified.

Technology Cost

No available information.

T0350

Global Technologies

Chloro-Cat Catalytic Oxidizer

Abstract

The Chloro-Cat™ catalytic oxidizer uses combustion followed by catalytic oxidation to treat halogenated organic vapors discharged from soil vapor extraction (SVE) and groundwater treatment systems. The system has been used in the field to treat a variety of volatile and semivolatile

organic compounds (VOCs and SVOCs). According to Global Technologies, the technology has been used at over 75 sites. The technology is currently commercially available.

According to the vendor, the benefits of Chloro-Cat include the following:

- Small equipment size
- Few construction materials required (lower cost)
- Low auxiliary fuel usage
- Low thermal stresses (resulting in longer equipment life)
- Ease of permitting
- Fuel flexibility
- Reliable safety mechanisms.

The oxidation of chlorinated compounds produces hydrogen chloride (HCl) along with the carbon dioxide and water vapor. Some catalyst aging data suggest that HCl exposure over 10,000 parts per million by volume (ppmv) for extended periods may lead to catalyst deactivation over time.

Technology Cost

A Chloro-Cat catalytic oxidizer was used with SVE at a Superfund Site in Deer Park, New York, to treat VOCs and SVOCs in soils. The total treatment cost for this application was $450,420. The costs associated with instrumentation were greater than anticipated due to corrosion of process duct work. Unit costs for this application were estimated to be $\$360/yd^3$ of soil treated (D13943P, p.192; D22776T, p.2).

Information Sources

D13943P, FRTR, 1995
D22776T, U.S. EPA, 1995

T0351

Golder Applied Technologies, Inc.

Hydraulic Fracturing/FracTool

Abstract

Golder Applied Technologies, Inc., has developed hydraulic fracturing technology using various methods including the patented FracTool drilling technique to improve permeability and promote remediation in contaminated soils. FracTool technology forms an integrated network of sand-filled fractures in the contaminated clays, glacial tills, and other fine-grained sediments. Hydraulic fracturing was first used in the oil industry as a method of increasing well yields. In environmental applications, hydraulic fracturing can increase recovery rates in both liquid and soil vapor extraction wells. The technology has been demonstrated in nine completed projects with a variety of soil types and is commercially available. The vendor estimates that its hydraulic fracturing technology can achieve site remediation where otherwise not possible and reduce the time required for remediation up to 67%.

The vendor claims the following advantages of its hydraulic fracturing technology:

- Increases effective radius of treatment wells leading to fewer wells required.
- Increases permeability of soil reducing treatment time.
- Increases removal of contaminants trapped in natural fractures and adjacent soils.

- Potentially allows for remediation alternatives by improving performance of in situ techniques.
- Potentially reduces capital and operating costs.

The maximum thickness that can be achieved by hydraulic fracturing is dependent on the fracturing fluid viscosity, the pressure applied, the stiffness of the ground, and, in an indirect way, formation permeability. Cemented sediments limit fracturing effectiveness. Ground deformation models are required to quantify the fracture geometry data acquired by surface sensors and monitor the growth of the created fracture. Care should be taken in using hydraulic fracturing around structures, due to ground heave associated with the process.

Technology Cost

In 1995, Golder Applied Technologies estimated the total cost of fracturing and well installation for a hydraulic fracturing project at Regina, Saskatchewan, at $55,000. A total of 96 fractures were installed on site in seven wells, and the estimated amount of soil treated was 6600 metric tons. The cost per fracture was $575, or $17/m^3, $8 per metric ton (D10587D, p. 5).

For another site in Regina in 1995, a total cost for 11 fractured wells, two soil vapor extraction systems and operation and maintenance for 6 months was approximately $80,000. This figure did not include vapor treatment since none was required. Golder estimated that the hypothetical cost of excavating and disposing of the 6000 yd^3 of contaminated soil at the Regina site would have ranged from $180,000 to $360,000. The costs would depend on disposal prices, backfill requirements, and water-handling requirements (D13865S, p. 9).

For a cost analysis, Golder presented data on the treatment of a spill 400 ft wide by 100 ft long and 25 ft thick containing 50 parts per million (ppm) benzene, toluene, ethylbenzene, and xylene (BTEX). Golder estimates that installation of 3 fractured wells would cost approximately $30,000, while installation of 6 unfractured wells would cost approximately $60,000. The total cost of unfractured wells over a predicted 35-year life span would be $351,000. It was estimated that treatment using fractured wells would only require 12 years, at a cost of $240,350. This amounts to a savings of approximately 30% (D13865S, p. 11).

According to information supplied by the vendor in 1996, costs for processing wastes using hydraulic fracturing depend on several factors, including site location, nature, type, and depth of contaminant, number of fracture wells, and the amount of sand required. The cost per fracture decreases as the number of fractures increases. Golder also expects the cost of fracturing to decrease as further experience is gained on the technology, and project designs improve (D10587D, p. 5).

Information Sources

D10587D, Leach, 1995

D13865S, Frere and Baker, 1995

T0352

Golder Associates Corporation

Montan Wax Barrier

Abstract

Montan wax is a fossil plant wax with properties similar to natural plant waxes such as those found in carnauba palms. The material is a hard and has a high melting point. Montan wax is composed of a mixture of waxes, resins, and asphaltene-like materials. The wax is typically used in carbon inks, emulsions, polishes, and lubricants.

A montan wax/bentonite clay emulsion has been used to create an in situ containment barrier in soils. The barrier limits the migration of water and waterborne contaminants through soil formations. The emulsified grout can be injected from the surface using conventional injection equipment. This eliminates the need for excavation and mixing. According to the vendor, this technology is not yet commercially available, but initial field trials have been completed.

According to the developer, advantages of montan wax include the following:

- Is chemically resistant to changes in pH, while cement grout tends to be broken up by either high or low pH.
- Tends to set harder and is more resistant than typical paraffins used for candles.
- Does not require soil excavation for installation.
- Able to reduce hydraulic conductivity by as much as 5 orders of magnitude.
- Is compatible with most types of hazardous wastes.
- May be applicable where conventional barrier construction methods are not feasible.
- Is flexible and does not contract.
- Does not degrade over time.

Montan wax is a containment technology; it does not remediate wastes. Montan wax grout is not chemically compatible with ethylene glycol waste material. The wax is also unsuitable for soils containing a high percentage of silt and clay. Sites with high water content may cause processing difficulties.

A montan wax barrier is difficult to install. High injection pressures are required emplace the barrier in soils. Injection is limited by how much the underlying rock can be fractured. The breakdown of the montan wax emulsion is difficult to control. As the mixture separates, the viscosity of the wax increases making injection virtually impossible.

Technology Cost

According to the vendor, the costs of montan wax are comparable to the costs for cement grout walls. The material, however, must be imported from Germany. As a result, this increases the cost (D11672D, p. 12).

Information Source

D11672D, Ground Water Monitor, January 26, 1995

T0353

Golder Associates Corporation

Vertically Oriented Hydraulic Fracture Placed Iron Reactor Walls

Abstract

Zero-valent iron reactive walls have been proven capable of remediating groundwater contaminated with halogenated hydrocarbons. Golder Associates Corporation has developed a vertically oriented hydraulic fracturing technology that can be used to place iron reactor walls. According to the vendor, this emplacement method allows walls to be emplaced to far greater depths than are possible with other installation methods at a significant cost savings. The vendor states that full-scale pilot studies are currently underway to emplace permeable iron reaction walls using the vertically oriented hydraulic fracturing technology. The technology is commercially available.

The maximum thickness that can be achieved by hydraulic fracturing is dependent on the fracture fluid viscosity, fracture containment pressure, and ground stiffness. The formation permeability also indirectly controls fracture thickness since in formations of extremely low permeability, high induced pore pressures will be a limiting factor.

Technology Cost

The vendor states that iron reactive walls installed by vertically oriented hydraulic fracture technology would have lower materials and installations costs than conventional funnel and gate systems (D176958, p. 7).

Based on 1997 data, the estimated cost of a permeable reactive barrier (PRB) system ranged from approximately $405,000 (corresponding to $1400 per 1000 gal of groundwater extracted) to $585,000 (corresponding to $225 per 1000 gal of groundwater extracted). The capital costs ranged from $373,000 to $500,000 and operation and maintenance (O & M) costs ranged from $32,000 to $85,000. Treatment wall costs included system construction, installation, monitoring, and analysis. Costs may vary due to differences in the subsurface matrix, thickness, and composition of wall (D18882D, pp. 133, 145).

Massachusetts Military Reservation, Falmouth, Massachusetts. Golder Associates Corporation is also involved in a full-scale pilot project at the Massachusetts Military Reservation (MMR), near Falmouth, Massachusetts. Two permeable barriers were emplaced at the site using hydraulic fracturing. Installation cost of the demonstration was estimated to be $160,000. This cost included design, construction, and the reactive media (D206235, p. 2).

Caldwell Trucking, New Jersey. A full-scale permeable reactive barrier system was installed at Operating Unit (OU) 2 of the Caldwell Trucking Superfund Site in northern New Jersey in 1998. The permeable barrier was installed into unconsolidated sands and fractured basalt using a combination of hydraulic fracturing and permeation infilling. The barrier system extended from 15 ft below ground surface (bgs) to 50 ft bgs. The system consisted of two 3-inch walls 150 and 90 ft in length. The barrier was constructed using 250 tons of zero-valent iron as the reactive material. Costs of the barriers were $670,000 for the 90-ft wall emplaced using hydraulic fracturing, and $450,000 for the 150-ft barrier constructed using permeation infilling. These costs included design, construction, materials, and the reactive material (D203747, p. 1).

Information Sources

D176958, Hocking and Wells, 1997

D18882D, Federal Remediation Technologies Roundtable, 1998

D206235, Remediation Technology Development Forum, 1998

D203747, Remediation Technology Development Forum, 1998

T0354

Grace Bioremediation Technologies

Daramend

Abstract

Daramend™ is a commercially available, amendment-enhanced, bioremediation technology designed to degrade organic compounds in soils and dewatered sediments. The process consists of three integrated components: amendment addition, specialized tilling, and a soil moisture control system. The technology can be applied to soils in situ or ex situ. Daramend accelerates degradation of the target compounds by combining contaminated soil with solid-phase, organic, and inorganic soil amendments of specific particle size and nutrient content.

Contaminants treated by the Daramend bioremediation technology include heavy oils, chlorinated phenols (CPs), polynuclear aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPH), and phthalates. The vendor claims the Daramend technology can be used to treat soils containing concentrations of CPs and PAHs that are typically considered too toxic for bioremediation.

Ex situ bioremediation is generally used in landfarming. This involves placing the contaminated media in a treatment cell. During treatment, the soil is periodically tilled and the water content is monitored to assure complete bioremediation. in situ is much the same, only there is no treatment cell.

Advantages of the Daramend technology include the following:

- Complete contaminant destruction.
- Flexibility in implementation (in situ or ex situ, slurry phase or solid phase, treatment can be scaled to meet site needs).
- Cost efficient compared to other treatment systems.
- Contaminants can be treated at full strength without dilution.
- Degradation will continue even after application has stopped.
- More reliable than other bioremediation technologies because the organic soil amendments are specifically engineered for the soil type.
- No residue requiring disposal.

Limitations of the Daramend technology include the following:

- Can be limited by low temperatures, which slow or stop biological activity.
- Uniform distribution of product is difficult.
- May be infeasible when contaminant concentrations are excessively high.
- Process may be inhibited by high concentrations of halogenated organics, heavy metals, and soil pH less than 2.
- Slow compared to other treatment technologies.

Technology Cost

The U.S. Army Environmental Center (USAEC) conducted a pilot-scale demonstration of the Daramend technology at the U.S. Department of Defense's (DOD's) Joliet Army Ammunition Plant in Joliet, Illinois. Based on this demonstration, the USAEC estimated the costs associated with a full-scale application of the technology. The estimated costs were \$819/yd^3 for the treatment of 10,000 yd^3; \$504/yd^3 for the treatment of 50,000 yd^3; and \$476/yd^3 for the treatment of 100,000 yd^3 (D221476, p. 3).

The vendor has compiled several cost estimates for full-scale operations using the Daramend technology. The vendor claims the cost for ex situ treatment ranges from \$90 to \$170 per ton and the cost for in situ treatment ranges from \$55 to \$95 per ton (D17912Y, p. 20). According to the vendor, the cost associated with the second-generation Daramend treatment, which cycles between anaerobic and aerobic phases, will be slightly higher. This cost ranges between \$90 and \$195 per ton and depends upon project specifics (D16985B, p. 6). In 1998, the vendor estimated that the costs associated with the treatment of 2500 to 5000 tons of waste would range from \$52 to \$81 per ton (D20080W, p. 42).

Based on the Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration at the Domtar Wood Preserving Facility in Trenton, Ontario, Canada, the vendor estimated the costs associated with a full-scale application of the technology

TABLE 1 Estimated Full-Scale Remediation Costs Using the Daramend System

	In situ (6800 m^3)		Ex situ (1360 m^3)	
	$	%	$	%
Site preparation	70,600	11.4	172,650	18.0
Permitting and regulatory requirements	3,000	0.5	3,000	0.3
Capital equipment	9,600	1.5	8,500	0.9
Startup	140,000	22.6	28,700	3.0
Consumables and supplies	2,250	0.4	94,700	9.9
Labor	52,000	8.4	279,000	29.1
Utilities	—	—	2,100	0.2
Effluent treatment and disposal	—	—	—	—
Residuals and waste shipping and handling	316,000	51.0	340,000	35.4
Analytical services	20,000	3.2	20,000	2.1
Maintenance and modifications	—	—	6,000	0.6
Demobilization	5,700	0.9	4,600	0.5
Total	619,000	99.9	959,250	100

Source: Adapted from D17911X, p. 25.

TABLE 2 Site Preparation Costs

Cost Item	In situ (6800 m^3) ($)	Ex situ (1360 m^3) ($)
Treatment plot fabrication	45,000	55,000
Utility connections	2,250	9,750
Trailer rentals	6,550	30,400
Installation of fencing	16,800	7,500
Purchase and installation of 2 greenhouses	—	70,000
Total	70,600	172,650

Source: Adapted from D17911X, p. 26.

(D17911X). See Table 1 for estimated full-scale remediation costs using the Daramend system and Table 2 for site preparation costs.

After a pilot-scale demonstration at the Novartis pesticide site in Cambridge, Ontario, Canada, the vendor compiled a cost estimate for the treatment of the remaining 600 tons of waste located at the site. The projected costs added up to $73,000 or approximately $120 per ton (D20080W, p. 42).

In 1993, the Daramend process was used to treat 150 metric tons of sediment contaminated with polycyclic aromatic hydrocarbons (PAHs) from Hamilton Harbor. According to the vendor, the cost of this demonstration was approximately $26,250 or $175 per ton (D10085W, p. 15; D169839).

Daramend was used to treat approximately 100 m^3 of PAH-contaminated soil at the Pacific Place Coal Gasification Plant in Vancouver, British Columbia, Canada. According to the vendor, the costs for this demonstration were approximately $95 per ton (D10085W, pp. 18–20).

The cost of the Daramend process varies depending on the type and amount of contaminants present, the soil type, amount of contaminated soil, monitoring and pretreatment requirements, and the required cleanup levels. The location of the site can also affect the overall cost of the project. The site's climate and distance from the source of equipment, supplies, and personnel will influence the cost of the remediation project (D11494D; D20080W, p. 42).

Information Sources

D10085W, VISITT 4.0, undated
D11494D, The Hazardous Waste Consultant, 1995
D169839, Bucens, Seech, and Marvan, 1996
D16985B, Grace Dearborn, Inc., 1996
D17911X, U.S. EPA, 1996
D17912Y, Ferguson, 1997
D20080W, Federal Remediation Technologies Roundtable, 1998
D221476, U.S. Army Environmental Center, 2000

T0355

Granular Activated Carbon (GAC) — General

Abstract
Granular activated carbon (GAC) is a commercially available ex situ contaminant-removal technology that extracts contaminants from liquid and airstreams by adsorption. GAC is generally used to collect low levels of contaminants. It is typically used to remove organics but can also be used to adsorb and concentrate inorganics for further treatment or as a polishing treatment in conjunction with other remediation technologies. GAC has been used in remediation of municipal, industrial, and hazardous waste streams. According to the Environmental Protection Agency (EPA), GAC has been shown to effectively remove volatile organic compounds (VOCs), pesticides and herbicides, trichloroethene (TCE), and polychlorinated biphenyls (PCBs). It has also been shown to effectively remove heavy metals from waste waters. Once the GAC module is saturated with contaminants, the granules can be reactivated (by destruction of contaminants), regenerated (by desorption of contaminants), or discarded.

GAC treatment offers the following advantages:

- Proven technology.
- Applies to a wide variety of organic contaminants, as well as some inorganics and metals.
- GAC equipment generally has small space requirements and often can be used as mobile units.
- GAC can be regenerated and reused, allowing for the recovery of removed contaminants.
- GAC can be used in columns, unlike powdered activated carbon.

The following factors may limit the effectiveness of this technology:

- Relative humidity greater than 50% can reduce carbon capacity in vapor-phase adsorption.
- Elevated temperatures from soil vapor extraction (SVE) pumps (greater than 38°C or 100°F) inhibit adsorption capacity.
- Biological growth on carbon or high particulate loadings can reduce flow through the bed.
- Spent-carbon transport may require hazardous waste handling.
- Spent carbon must be disposed of and the adsorbed contaminants must be destroyed, often by thermal treatment.
- Some compounds, such as ketones, may cause carbon bed fires because of their high heat release upon adsorption.

Technology Cost
Costs associated with the use of GAC technology are dependent on waste stream flow rates, type of contaminant, concentrations, and site requirements. Costs decrease at lower contaminant

TABLE 1 Cost Estimate for Liquid-Phase and Vapor-Phase Activated Carbon Systems

Flow Rate	Capital Cost[a]	O & M Costs[b]	Cost/1000 gal
	Liquid-Phase Carbon System		
10 gal/min	\$5,000	\$7,100	\$1.40
50 gal/min	\$13,000	\$15,100	\$0.60
100 gal/min	\$20,000	\$22,300	\$0.40
300 gal/min	\$39,000	\$53,300	\$0.35
	Vapor-Phase Carbon System		
100 ft^3/min	\$6,000	\$2,700	\$0.55
500 ft^3/min	\$18,000	\$9,800	\$0.40
1,000 ft^3/min	\$36,000	\$19,200	\$0.35
3,000 ft^3/min	\$58,000	\$47,800	\$0.30

Source: Adapted from D16494X.

[a] Capital cost for the liquid-phase system is estimated based on using two pressure vessels on a prepiped, prewired skid, no installation included. Capital cost for the vapor-phase system is based on using two to four skid-mounted reusable carbon vessels with hose connections, initial fill of carbon, sizes of 400 lb, 2000 lb, and 10,000 lb as required for a rated flow rate at a 5-inch water pressure drop or less.

[b] Operation and maintenance (O & M) costs for the liquid-phase system are based on \$0.08/kWh hour power, \$10/hr labor for 1 hr/day, 360 annual days of operation, influent contaminant concentrations of 1 mg/liter, 5% absorption/weight, \$1.00/lb carbon, and a 5-year system life at 8% interest. O & M costs for the vapor-phase system are based on a >99% removal of all VOCs from water with an influent concentration of 1 mg/liter, 75:1 water to air ratio (volume based), 5% absorbency, \$10.00/hr operator, 40 hr/year changeover time, no power, no freight, 5-year system life at 8% interest, 5% capital for maintenance, and \$1.00/lb regeneration or replacement carbon.

concentration and at higher flow rates. Treatment rates of 100 million gallons per day (mgd) cost between \$0.10 and \$1.50 per 1000 gal treated, while flow rates of 0.1 mgd cost between \$1.20 and \$6.30 per 1000 gal treated (D14920M, p. 5).

Equipment costs for a vapor-phase GAC system typically range from less than \$1000 for a 100-standard cubic feet per minute (scfm) unit to \$40,000 for a 7000-scfm unit. Carbon costs are \$2 to \$3 per pound (D10944E, p. 4.224).

In 1995, the U.S. EPA estimated costs for liquid-phase carbon adsorption and vapor-phase carbon absorption (D16494X, p. 99). This information is presented in Table 1.

Information Sources

D10944E, U.S. DOD, 1996

D14920M, U.S. EPA, 1991

D16494X, U.S. EPA, 1995

T0356

Groundwater Recovery Systems, Inc.

OXY I

Abstract

OXY I is an oxygen injection system for remediation of organics-contaminated groundwater. The oxygen enhances biodegradation of the contaminants, particularly methyl tertiary butyl ether

(MTBE) and benzene, toluene, ethyl benzene, and xylene (BTEX), which are primary components of gasoline. Groundwater Recovery Systems, Inc. (GRS), is the sole licensed manufacturer of the OXY I system. Matrix Biotechnologies has had involvement with technical aspects of the units and is also a vendor of the technology.

The OXY I system consists of an oxygen generator that works with a receiver tank for oxygen storage prior to injection and a pulse sparging manifold. According to GRS, the system introduces pure oxygen into the groundwater by way of multiple injection points at flow rates subsequently lower than traditional air sparging. OXY I's relatively low injection rate per point and high transfer efficiency of oxygen into the groundwater negates the need for vapor control via vadose zone extraction, according to the vendor.

All information was provided by the vendor and could not be independently verified. This technology is only applicable to contaminants that can be biodegraded.

Technology Cost

A complete, trailer-mounted system costs between 35,000 and $38,000 (personal communication: G. Nolan, GRS, Inc., 1997).

T0357

GSE Lining Technology, Inc.

GSE CurtainWall Vertical Membrane Barrier System

Abstract

GSE Lining Technology, Inc., distributes high-density polyethylene (HDPE) vertical membrane barrier systems for in situ containment of groundwater, soil gases, and contaminated leachates. The GSE CurtainWall® is a commercially available system of HDPE panels joined by patented interlocks. HDPE binders can provide a continuity and relative impermeability that conventional grout and cement walls may lack. For remediation applications, the GSE CurtainWall is designed to prevent the migration of contaminant plumes and to isolate contaminated groundwater and leachate from other aqueous streams.

GSE CurtainWall is installed in a trench that can also house a collection of leak detection systems. The vendor claims that GSE CurtainWall systems have been installed to depths exceeding 130 ft. A hydrophilic rubber seal is inserted into one or more of the interlocking chambers to prevent migration of contaminants at the panel connections.

The vendor claims that CurtainWall has the following advantages:

- Flexible; conforms to subsurface soil movement and will not crack under stress.
- Durable and resistant to most chemicals.
- Confines liquids and gases.
- Able to obtain permeabilities as low as 2.7×10^{-12} cm/sec.
- Quick and economical installation.
- Long service life.

According to the U.S. Department of Energy (DOE), the main limitations of synthetic barriers are the potential for leakage at the seams, depth limitations, and increased costs in areas with high concentrations of boulders and cobbles. In addition, the long-term durability of HDPE is unknown. Another limitation is that the use of barriers often relies on the presence of an aquitard. For the purposes of this discussion, an aquitard is a region of low permeability that acts as a barrier to groundwater flow. The aquitard prevents the movement of contaminants and groundwater below the installed barrier.

Technology Cost

The cost of GSE CurtainWall technology varies depending on site conditions. The cost of the HDPE ranges from \$10 to \$30/ft^2 (D18980E, p. 17). According to the U.S. DOE, the cost of a synthetic barrier installation depends on the subsurface composition, depth, and method of installation. The DOE estimates that installation costs range from \$20 to \$250/m^3 (D17096R, p. 2).

Groundwater Control, Inc., an installer of the GSE CurtainWall system reports that costs for installation will vary dramatically and average around \$14/ft^2 installed (personal communication: Belinda Bursen, Vice President, Vertical Barriers Division, Groundwater Control, Inc., November 1997).

Information Sources

D17096R, U.S. DOE, undated web page
D18980E, Pearlman, 1999

T0358

GSE Lining Technology, Inc.

GSE GundWall Vertical Membrane Barrier System

Abstract

GSE Lining Technology, Inc., distributes high-density polyethylene (HDPE) vertical membrane barrier systems for the in situ containment of groundwater and soil gases. The GSE GundWall® is a commercially available, patented HDPE vertical barrier system made of interlocking panels. HDPE barriers can provide a continuity and relative impermeability that conventional grout and cement walls may lack. For remediation applications, the system is designed to prevent the migration of contaminant plumes and to isolate contaminated groundwater and leachate from other aqueous streams.

The technology is designed to be installed using one-pass deep trenching or trenchless construction methods. According to the vendor, GundWall panels can be vibrated up to 40 ft deep depending on soil type and consolidation. The GSE GundWall interlock consists of male and female HDPE profiles that function as a dovetail joint. The interlock is sealed by a hydrophilic gasket that forms a barrier to groundwater flow.

The vendor claims that GSE GundWall has the following advantages:

- Allows for and conforms to subsurface soil movement.
- Offers resistance to most chemicals.
- Confines liquids and gases.
- Provides durable protection with a long service life.
- Offers resistance to rodent attack.
- Does not exhibit environmental stress cracking.

According to information from the U.S. Department of Energy (DOE), the main limitations of synthetic barriers are the potential for the barrier to leak at the seams, depth limitations, and increased costs in areas with high concentrations of boulders and cobbles. Another limitation is that the use of barriers often relies on the presence of an aquitard. For the purposes of this discussion, an aquitard is a region of low permeability that acts as a barrier to groundwater flow. If no aquitard is present at the base of the installed barrier, groundwater can simply flow under it.

Technology Cost

The cost of GSE GundWall vertical membrane barrier system technology will vary with site conditions. According to information published by the U.S. DOE, the factors influencing the cost of synthetic barrier installation include the presence of boulders and cobbles in the soil and the depth of installation. The DOE estimates that installation costs can range for \$20 to \$250/m^3 (D17096R, p. 2).

Groundwater Control, Inc., an installer of the GSE GundWall system reports that costs for installation will vary depending on soil characteristics, depth and length of wall, and drilling technique. Costs can range from \$9 to \$15/ft^2 for the trencher method and for the vibratory method costs can range from \$12 to \$25/ft^2 (D20300P, p. 28).

Information Sources

D17096R, U.S. DOE, undated web page

D20300P, Pearlman, 1999

T0359

GTS Duratek

DuraMelter

Abstract

GTS Duratek has developed the DuraMelter™ system for the treatment of hazardous, radioactive, and mixed wastes. The system uses heat generated between electrodes (joule heating) to melt and oxidize organic waste compounds and melt inorganic contaminants. DuraMelters operate under relatively low temperatures for a vitrification technology (typically 1150°C) and form wastes into a durable, leach-resistant glass. DuraMelter systems are commercially available in several different sizes. GTS Duratek can provide customized melters to meet specific waste treatment needs.

Duratek claims the following advantages of DuraMelter technology:

- Accommodates a wide range of waste compositions.
- Treated wastes are bound in a durable, leach-resistant glass.
- Units stabilize their own off-gas scrubbing and filtration waste, thus preventing the creation of secondary waste streams.
- In many cases the wastes can be delisted as hazardous.
- Substantial waste volume reductions are possible.

A limitation of this technology is that at least some additives are normally required before processing to control the properties of the final waste form. Since only a small part (approximately 30%, according to the vendor) of the waste is incorporated into the final glass product, most of the material is converted to gases and particulate that must be processed by the off-gas system.

Technology Cost

DuraMelter technology was evaluated as part of the Minimum Additive Waste Stabilization (MAWS) program by the U.S. Department of Energy's (DOE's) Office of Technology Development (OTD) in 1993. The OTD prepared a cost analysis as an initial scoping estimate for the remediation of the DOE facility at Fernald, Ohio. It was reported that the remediation would cost from \$700 to \$1300/yd^3 of wastes, compared with an estimated cost of \$1500 to \$3000/yd^3 if cement solidification was used. This would yield a potential cost savings of a minimum

TABLE 1 Cost Estimate Comparison of Vitrification and Cement Stabilization for U.S. Department of Energy Mixed Waste at the Fernald, Ohio, Site

Category	Vitrification	Cement Stabilization
Engineering and design costs	\$10,000,000	\$10,560,000
Construction costs	\$153,355,000	\$161,935,000
Operations costs	\$193,275,000	\$463,147,000
Maintenance costs	\$61,500,000	67,678,000
Decommissioning and decontamination, greenfielding, and monitoring costs	\$32,800,000	\$37,184,000
Total treatment costs	\$450,930,000	\$740,504,000
Total disposal costs	\$107,586,000	\$536,795,000
Total costs	\$558,516,000	\$1,277,299,000
Waste treatment costs/yd^3	\$809.57	\$1,329.45
Waste disposal costs/yd^3	\$193.15	\$963.72
Percent savings by vitrification = 56.27		

Source: Adapted from D114432.

of \$100 million for the Fernald remediation. The engineering confidence in these analyses is +30/−50% and apply only to the remediation of the Fernald site (D114432, Appendix A). A summary of cost categories is given in Table 1.

The assumptions used for this estimate are listed in Appendix A of D114432. Among these assumptions were that all of the wastes contained at the Fernald site would be treated in the same manner with the selected treatment scenarios. Soil washing would be used to reduce the volume of materials that required treatment. Near site disposal costs were estimated to be \$258/yd^3 for the final waste form (D114432, Appendix A).

For the cement stabilization option, a facility would be constructed to dewater and treat the wastes. There would be a 7- to 21-day staging period of wastes for quality assurance operations. An online rate of 250 days a year was assumed. It is estimated that cement stabilization would result in a volume factor increase roughly 3.75 times the total volume of waste treated. This increase in volume is necessary to immobilize technetium present in the wastes and to achieve a final waste form that could withstand pressures of 500 pounds per square inch (psi). The cement would be placed in 4-ft by 4-ft by 8-ft steel containers that would serve as a mold and to facilitate the handling of the finished blocks (D114432, Appendix A).

It was estimated that the vitrification option would allow for a volume decrease of 0.75 as a conservative estimate, and that the actual volume decrease could be 0.50. Wastes would be treated in four equally sized melter systems, each of which would process about 80 tons per day. The project would be completed in about 10 years. The online operational rate is projected to be 75%, with three normally operating systems and one system down for maintenance. The produced glass does not require placement in containers, as it will pass leach test requirements in that form (D114432, Appendix A).

OTD estimated that cement stabilization would produce 2,080,600 yd^3 of stabilized wastes that could not be delisted and would have to be stored as mixed waste. The Duratek vitrification system would generate 417,000 yd^3 of waste that may meet criteria for delisting as hazardous wastes and could be stored as only radioactive wastes (D114432, Appendix A).

Most of the cost data for vitrification technologies are estimates based on pilot-scale operations. Such data are suspect because they are based more on extrapolation than on experience. Such estimates are difficult to compare because the assumptions on which they are based may vary widely (D18248T, p. 55).

Many site-specific characteristics have an impact on vitrification technologies. One critical aspect of any thermal technology is the water content of the waste. Water dilutes feed material, requires energy to drive off, and physically limits the feed rate of waste. Feed preparation is another variable, which differs with the technology and with site-specific characteristics. Some technologies can accept complete barrels of waste at a time, while others require pretreatment and size reduction. Many estimates do not take into account site preparation and waste disposal costs. Only complete treatment life-cycle assessments can provide reliable comparison data, and such studies are, by definition, highly site and waste specific (D18248T, p. 55).

Various sources estimate vitrification costs as ranging from under $100/ton to over $1000/ton for units treating hazardous waste. These estimates are assumed to be for treatment only, not including pretreatment and disposal costs. The extreme variability of the costs may be attributable to differences in feed type and water content of the waste (D18248T, p. 55).

Information Sources

D114432, U.S. DOE, 1994

D18248T, Sigmon and Skorska, 1998

T0360

H & H Eco Systems, Inc.

Microenfractionator

Abstract

The Microenfractionator™ (also called Turbo-Rator™) is a soil mixing technology that is used to homogenize contamination, free trapped contaminants, and combine the soil with treatment reagents. The technology is often used as part of a three-pronged soil treatment system that combines biological nutrients, chemical surfactants, and the Microenfractionator to remediate soils contaminated with volatile organic compounds (VOCs) and total petroleum hydrocarbons (TPH). The Microenfractionator may also be used to add other reagents to the soil, including zero-valent iron, reductive agents, the company's proprietary Solid State Chemical Oxidation (SSCO™) compound. The technology is currently commercially available.

According to the vendor, Microenfractionator technology offers the following advantages:

- Achieves 85 to 95% homogenization.
- Eliminates areas with large contaminant variation.
- Treats 400 to 600 yd^3 of soil per hour.
- Eliminates anaerobic areas by entraining oxygen in the soil.
- Reduces the required frequency of mixing operations.
- Operates very economically on a per cubic yard basis.

The chemical component of the cleanup system, Simple Green, is not well-suited for use with hydrocarbons that are solids at room temperature.

Technology Cost

According to the vendor, the Microenfractionator unit can cost up to $350,000 for a fully loaded unit or $170,000 (1993 dollars) on a 5-year purchase-to-own lease basis. The cost to use this technology is estimated to be $12 to $13 (1993 dollars) per cubic yard of soil treated (D14773T; D21577K, p. 8).

The treatment costs for 2.5 million pounds of soil contaminated with metolachlor at a site in southwest Nebraska were estimated to be $65,000. The treatment involved using a Microenfractionator to mix the excavated soil with zero-valent iron and water. The estimate included labor costs (D21578L, p. 2).

Information Sources

D14773T, The Bioremediation Report, Vol. II, No. 3, March 1993

D21577K, The Seattle Daily Journal of Commerce, 1998

D21578L, Water Current, 2000

T0361

H & H Eco Systems, Inc.

Solid-State Chemical Oxidation

Abstract

Solid-state chemical oxidation is an ex situ technology that combines strong oxidizers and catalysts with contaminated soil. This technology is used in conjunction with the Microenfractionator™. The Microenfractionator is used to provide the level of soil mixing necessary to adequately homogenize the soil in a solid state (as opposed to a liquid slurry) to ensure contact between the contaminant, catalyst, and oxidizing agent.

According to the vendor, this technology can treat the following contaminants:

- Explosives
- Wood preservatives [creosote and pentachlorophenol (PCP)]
- Chlorinated pesticides and herbicides
- Chlorinated solvents
- Polycyclic aromatic hydrocarbons (PAHs)
- Petroleum products

According to the vendor, solid-state chemical oxidation technology is currently commercially available. The vendor has supplied performance information for full-scale cleanups.

In April 2001, the U.S. Environmental Protection Agency (EPA) published a citizen's guide to chemical oxidation technologies. EPA lists the following advantages of chemical oxidation technologies:

- Destroys organic contaminants.
- Operates more quickly than other techniques (in months, rather than years).
- Treats higher contaminant concentrations than bioremediation methods.

Chemical oxidation technologies can produce toxic by-products and reduce biomass. When using chemical oxidation methods, the reaction rate of the process must be carefully controlled. Due to the exothermic nature of many oxidation reactions, the heat and energy released during treatment has the potential to cause explosive reactions.

Technology Cost

Solid-state chemical oxidation technology is generally applied using H & H Eco Systems, Inc., Microenfractionator technology or using a masticator. According to vendor information published in 1998, a masticator costs between $85,000 and $250,000 depending upon capacity. A Microenfractionator unit can cost up to $350,000 (D21577K, p. 3).

Although many of the costs for chemical oxidation technologies will be site specific, chemical costs will generally average 15 to 30% of the total remediation costs. Factors that influence chemical costs will include the chemical oxygen demand (COD) of the contaminated media, pH, the size of the site, and initial contaminant concentrations (D22442A, pp. 19, D-1)

Information Sources

D22442A, Interstate Technology and Regulatory Cooperation Work Group, 2001

D21577K, Seattle Daily Journal of Commerce, 1998

T0362

Halliburton NUS

Soil Saw

Abstract

Soil Saw™ is an in situ containment technology that creates barrier walls to limit the migration of contaminated groundwater. Barriers are constructed "in place" without the excavation of soil. This technology utilizes a rigid beam, containing jets of cement grout or bentonite slurry, which is reciprocated through the soil. The combined sawing and jet action pulverizes and liquefies the soil, mixing it with grout, which later hardens to form a plastic diaphragm wall.

According to the vendor, walls can be constructed to depths of up to 180 ft. The vendor claims that since the in situ construction does not require backfill, problems associated with incomplete wall construction (areas back filled with untreated soil) are eliminated.

According to Halliburton NUS, this technology is not currently commercially available.

Researchers state that Soil Saw barrier technology offers the following potential advantages over conventional slurry wall barrier techniques:

- Allows for in situ mixing.
- Minimizes required excavation.
- Accelerates emplacement process.
- Decreases secondary waste volume.

According to the vendor, fluid introduced into the soil may create excess slurry. For example, it is anticipated that the creation of a barrier in hard soils may result in an overflow slurry measuring up to one half of the volume of the trench. Researchers state that barriers are limited by the depth and directional control of the drilling technology and limited by the ability on nonintrusive techniques to verify barrier continuity.

Technology Cost

According to the vendor, the Soil Saw's existing hardware is only suited for large projects: many thousands of feet in length and over 20 ft deep. Mobilization costs can run up to $50,000 and daily operations can cost about $30,000 per day plus bulk materials. Materials cost about $0.50/ft^3$ for bentonite walls to several dollars for cement grout walls. Materials for a cement bentonite wall may cost $1.00/ft^3$ and up. At an average operating rate of 2500 ft^2/hr, working 7 hr per day the system should be able to install walls at costs of about $2/ft^2$ plus materials (D15711J, p. 606).

Information Source

D15711J, Carter, 1996

T0363

Harding ESE, Inc.

PetroClean Bioremediation System

Abstract
Harding ESE, Inc. (formerly Environmental Science and Engineering, Inc., QST, Inc., and ESE Environmental, Inc.), developed the patented PetroClean® bioremediation system for the in situ treatment of organic contaminants in soils and groundwater. The technology recovers and treats the groundwater in an aboveground, fixed-film bioreactor containing acclimated indigenous microbes, nutrients, and oxygen. The groundwater is then flushed through subsurface soils, thereby enhancing the environment for contaminant-degrading microbes in both the soils and the groundwater. The PetroClean bioremediation system is designed to recover the flushed groundwater to create a closed-loop, in situ, remediation system that treats soils and groundwater simultaneously.

The PetroClean bioremediation system treats biodegradable contaminants (i.e., gasoline, diesel fuel, aviation fuel, solvents, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), total petroleum hydrocarbons (TPH), and other organic compounds in soils and groundwater.

The technology has been used in the following industries: dry cleaning, gasoline/service station, petroleum refining and reuse, organic chemical manufacturing. According to the vendor, the technology can be used in herbicide manufacturing/use, industrial landfills, inorganic/organic pigments, machine shops, municipal landfill, munitions manufacturing, paint/ink formulation, pesticide manufacturing/use, photographic products, plastics manufacturing, pulp and paper industry, and wood preserving.

One advantage of the technology is that it treats both groundwater and soil simultaneously. Separate systems are not required for the treatment of different media.

Removal rates for the PetroClean bioremediation system are governed by the solubility of the contaminants and by the ability of indigenous microbes to degrade contamination. Additional problems that could affect the PetroClean system might include clogging, subsurface permeabilities, permitting problems, and regulations on the nutrients used in the process.

In late 1998, the vendor noted that this technology is no longer available from this company.

Technology Cost
The vendor estimates that the overall cost for using the PetroClean bioremediation system ranges from \$50,000 to \$200,000, depending on the site (personal communication: Doug Leonard, QST Environmental, Inc., December 1996).

Among the factors that affect unit prices are (D10107L, p. 33):

- Initial contaminant concentration
- Quantity of waste
- Depth of contamination
- Soil characteristics
- Target contaminant concentration
- Depth to groundwater
- Site preparation

The following cost information was taken from the indicated case studies:

1. *Camp Grayling Army Airbase, Grayling, Michigan.* The PetroClean system remediated approximately 11,700 yd^3 of contaminated soil at a cost of \$30/yd^3. The system recovered

and treated approximately 15 million gallons of contaminated groundwater at no additional cost (D13728K, p. 3).

2. *Industrial Cleaning Facility, California.* The PetroClean bioremediation system remediated 4600 m^3 of contaminated soil at a cost of approximately \$59/m^3. The system also recovered and treated an additional 5.7 million liters of contaminated groundwater at no additional cost (D12884R, pp. 598–599).
3. *Planters Lifesavers Company (former solvent disposal area), Suffolk, Virginia (D13727J, p. 2).* The PetroClean bioremediation system treated 2,800,000 gal of groundwater (in situ) at a total project cost of \$400,000 (\$67 per ton of treated material) (D10107L, pp. 19–20).
4. *Dry Cleaning Site, Riverside, California.* The PetroClean bioremediation system treated 2,000,000 gal of groundwater and light non-aqueous-phase liquid (LNAPL) at a total project cost of \$270,000 (D10107L, pp. 8–12).

Information Sources

D13728K, QST Environmental, Inc., date unknown
D12884R, E.K. Schmitt et.al., date unknown
D13727J, QST Environmental, Inc., date unknown
D10107L, VISITT 4.0

T0364

Harding ESE, Inc.

Bioremediation — Landfarming Treatment

Abstract

Harding ESE, Inc.'s, landfarming treatment is an ex situ technology that uses indigenous bacteria to remediate contaminated soils or sludges. The commercially available technology can be used on-site to treat excavated soils or sludges contaminated with petroleum and other biodegradable chemicals.

The landfarming technology does not treat metals, nonbiodegradable organic chemicals such as DDT, or highly volatile chemicals such as benzene or chlorinated solvents. All information has been supplied by the vendor and has not been independently verified.

Technology Cost

The vendor estimates the price range of the landfarming treatment technology to be \$25 to \$50/yd^3. The actual price of a remediation project varies due to the initial concentration of the contaminants, the target concentration of the contaminants, the soil characteristics, the quantity of the waste, and the moisture content of the soil (D10005G, p. 25; D213718, p. 3).

Approximately 3000 yd^3 of soil contaminated with polycyclic aromatic hydrocarbons (PAH) was treated using this technology at an oil refinery in Perth Amboy, New Jersey. The vendor estimated that the cost of this project was \$50/yd^3 (D213718, p. 8).

According to the vendor, landfarming was used to treat 10 yd^3 of soil contaminated with PAH from a coal gasification plant in Connecticut. The cost of this pilot-scale demonstration was approximately \$80/yd^3 (D213718, p. 6).

Information Sources

D10005G, VISITT 4.0, 1995
D213718, U.S. EPA Reachit, undated

T0365

Harding ESE, Inc.

Composting

Abstract

The Harding ESE, Inc., composting technology is an ex situ process intended to treat soils, nonmunicipal sludges, and sediments contaminated with petroleum, coal tars, and munitions. The technology may also be used to modify the texture of soil with low permeability by using bulking agents.

In the composting process, the contaminated soil, sediment, or sludge is mixed with wood chips or other suitable bulking agents to increase the contaminated media's permeability to air. Special equipment for mixing the media and the bulking agents is required for appropriate blending. The mixed material is then placed into compost piles. After the compost piles are formed, periodic mixing is necessary to control the temperature and to ensure that sufficient oxygen is provided.

According to the developer, the technology is applicable in the coal gasification and the petroleum refining and reuse industries and has potential applications in the following industries: agriculture, gasoline/service station, herbicide manufacturing/use, munitions manufacturing, pulp and paper industry, organic chemical manufacturing, and wood preserving.

The developer claims that one advantage of composting is that it is more effective than other solid-phase treatment systems for soils and sludges contaminated with viscous substances such as coal tar, creosote, or petroleum production facility sludges and still bottoms.

Soil treatment using composting systems is limited to biodegradable chemicals. The technology cannot treat metals and most other inorganic chemicals (except cyanide). Additionally, the technology cannot readily biodegrade halogenated chemicals.

Technology Cost

According to the developer, the cost for using the Harding ESE, Inc., composting technology ranges from \$25 to \$100/yd^3 of material treated (D10004F, p. 20).

The following factors affect the cost of the technology (D10004F, p. 20):

- Initial contaminant concentration
- Target contaminant concentration
- Site preparation
- Waste handling/preprocessing
- Soil characteristics
- Waste quantity
- Moisture content of the soil

Information Source

D10004F, VISITT 4.0

T0366

Harding ESE, Inc.

Forced Aeration Contaminant Treatment (FACT)

Abstract

Composting is the biodegradation of organic materials by microorganisms. The process results in the production of organic and inorganic by-products and the generation of heat. Composting can be promoted through the incorporation of bulking agents to provide drainage and penetration of air. Static-pile composting uses an aeration/heat removal system to increase control over the composting system. The Forced Aeration Contaminant Treatment (FACT^{TM}) is a static-pile composting system that utilizes a perforated pipe to supply oxygen to soil microbes within the pile.

FACT is an ex situ process that treats all biodegradable semivolatile organics compounds (SVOCs) including petroleum-contaminated soil. It has an advantage over other bioremediation technologies such as landfarming, in that it requires less space to degrade contaminants.

The composting system effectively remediates soils that are heavily contaminated and cannot be treated by in situ methods as well as wastes containing hazardous volatile constituents untreatable by land farming methods.

FACT is limited to treating biodegradable contaminants. It cannot treat metals, inorganic contaminants, or halogenated compounds. For sludge-type soils that are heavily contaminated with tar, some texture modification may be required prior to treatment.

Technology Cost

The vendor estimates the price range of FACT to be \$25 to \$75/yd^3. The cost of treating 3000 yd^3 of soil for Boys Supermarket in Los Angeles, California, was \$75/yd^3. According to the vendor, factors affecting cost include initial and target contaminant concentrations, site preparation, and amount of waste (D10006H, pp. 10, 13).

Information Source

D10006H, VISITT 4.0, 1995

T0367

Harding ESE, Inc.

In Situ Vadose Zone Soil Treatment

Abstract

The Harding ESE, Inc., in situ vadose zone soil treatment uses indigenous bacteria and formulations of mineral nutrients to treat biodegradable chemicals in soil. The technology only treats contaminants in the soil's vadose zone (the zone below the surface but above the water table; also known as zone of aeration).

The technology can primarily be used to treat petroleum and other readily biodegradable chemicals that are found in the upper 6 ft of soil and can potentially treat sediment in situ.

Among the industries where the technology is applicable are petroleum sites, pulp and paper manufacturing, and wood preserving. The technology can potentially be used at coal gasification plants.

According to the technology developer, the technology has the following limitations:

- Cannot treat metals and other nonbiodegradable chemicals.
- Cleanup goals are generally long term because remediation using the technology is slow.

Technology Cost

According to the technology developer, the cost for using the Harding ESE, Inc., in situ vadose zone soil treatment ranges from \$25 to \$75/yd^3 (D10003E, p. 30).

The cost for using the technology at several sites is summarized below (see Case Study Overview):

- Seymour Recycling Site in Seymour, Indiana: Cost ranged from \$50 to \$100/yd^3 to remediate 190,000 yd^3 of soil (in situ) in a full-scale cleanup where the site was contaminated with total petroleum hydrocarbons (TPH) (D10003E, pp. 8–12).
- Florida Power & Light in Fort Meyers, Florida: Cost \$50/yd^3 to remediate 1500 yd^3 of soil (in situ) in a full-scale cleanup; site was contaminated with Number 6 fuel oil (TPH) (D10003E, pp. 13–17).
- Gas station in Massachusetts: Cost \$65/yd^3 to remediate 500 yd^3 of soil (in situ) contaminated with weathered Number 4 fuel oil (D10003E, pp. 18–22).

Among the factors that significantly affect the cost are:

- Initial contaminant concentration
- Target contaminant concentration
- Waste quantity
- Moisture content of soil
- Waste handling/preprocessing
- Soil characteristics (D10003E, p. 30)

Information Source

D10003E, VISITT 4.0

T0368

Harding ESE, Inc.

Two-Zone Plume Interception Treatment Technology

Abstract
The two-zone plume interception treatment technology is designed to treat chlorinated and nonchlorinated organic compounds in groundwater using a sequence of anaerobic and aerobic conditions. The in situ technology has been applied to aquifers contaminated with benzene, toluene, ethylbenzene, and xylenes (BTEX); petroleum products; hydrocarbons; coal tar wastes; and industrial feedstock chemicals. The technology does not treat metals.

The vendor conducted bench-scale tests with the U.S. Environmental Protection Agency (EPA) from 1991 to 1994 under the Superfund Innovative Technology Evaluation (SITE) Emerging Technology Program. According to the vendor, field testing is currently underway.

Technology Cost
According to the vendor, the two-zone plume interception treatment technology is more cost effective than the pump-and-treat method because the contaminants are destroyed on-site and the costs associated with removal, transport, recovery, or incineration are avoided (D10002D, p. 2).

During the pilot-scale field demonstration in Watertown, Massachusetts, two-zone plume interception treatment technology was used to treat a 10-ft-by-20-ft surface area of groundwater contaminated with trichloroethene (TCE) and tetrachloroethene (PCE). The total costs of the project from November 1996 through November 1997 were approximately \$150,000 (D21041T, p. 104).

Information Sources

D10002D, VISITT 4.0, 1995
D21041T, Federal Remediation Technologies Roundtable, 2000

T0369

Heaven from Earth, Inc.

Organic Cleaners

Abstract
The Heaven from Earth, Inc., organic cleaners can be used to clean and decompose hydrocarbons and selected industrial wastes in soil. The Neozyme product line includes cleaners for wastewater treatment, tank and bilge water treatment, and an odor control solution. According to the vendor, the technology is based on a broad array of special enzymes and coenzymes to greatly increase the speed at which contaminants will be decomposed. The ingredients in the solutions are water, purified proteins from plants, and mineral sources. The solutions are commercially available. According to the vendor, the solutions are biodegradable, nontoxic, nonirritating, and nonflammable. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0370

High Mesa Technologies, L.L.C.

Silent Discharge Plasma

Abstract
Los Alamos National Laboratory (LANL) has developed silent discharge plasma (SDP) technology for the ex situ treatment of vapors and hazardous off-gases containing volatile organic compounds (VOCs). In SDP technology, a nonthermal plasma is created by electrical discharges. The plasma breaks down water molecules into hydroxyl and hydrogen free radicals. These radicals are highly reactive and can be used to destroy organic contaminants in vapors.

In 1992, LANL and the Electric Power Research Institute (EPRI) entered into a cooperative research and development agreement (CRADA) to transfer SDP to industry. Through a competitive call for proposals, High Mesa Technologies, L.L.C. (HMT) of Santa Fe, New Mexico, subsequently was selected as the third partner to commercialize and develop SDP equipment. HMT has also licensed the rights to use SDP technology for process off-gas control. In February 1997, it was reported that HMT was seeking opportunities to demonstrate a commercial SDP system for industrial off-gas treatment and anticipated that commercial units would be available in 12 to 18 months.

According to data provided by LANL, SDP technology has the following advantages:

- Allows scaling to a wide range of treatment capacities.
- Treats many different contaminants simultaneously.

- Allows for a higher degree of hazardous compound removal.
- Operates at ambient temperature and pressure.
- Costs less than some competing technologies.

SDP systems require a gaseous feed, but they can be used in combination with another remediation technology, such as a packed-bed reactor, to treat other waste streams. SDP performance and cost are contaminant specific.

Technology Cost

In 1993, the U.S. Department of Energy's (DOE's) LANL estimated that the operating cost of SDP was less than a dollar per kilogram for the remediation of vapor contaminated with 500 parts per million (ppm) of trichloroethylene (TCE). This estimate assumes an operating efficiency of 30% for the SDP cells and an electricity cost of $0.10/kWh (D13528E, p. 5386). LANL estimates that SDP technology is 2 to 4 times cheaper per kilogram than activated carbon for the remediation of VOCs (D13140Y, p. 2).

In a 1996 report compiled by LANL, cost estimates were prepared for seven innovative off-gas treatment technologies as well as for three off-gas technologies currently in use. Results of the estimate for SDP are summarized in Table 1. It was estimated that SDP was most cost effective in treating high concentrations of specific contaminants at low flow rates. It was found that cost was independent of VOC concentration but was dependent on the desired destruction and removal efficiency (DRE) and the flow rate. Energy costs drop for gas matrices other than air (e.g., off-gas from a pyrolizer or low-temperature desorber or gas streams carried by an inert gas such as argon) (D130756, p. 21).

Costs were found to be contaminant specific. Capital costs are generally proportional to flow rate because the capital cost of the power supply is the most expensive power component. Treatment of perchloroethylene (PCE) required three times more electrical power than treatment of TCE. Destruction of carbon tetrachloride required even more energy, but isopropanol was readily destroyed using very little power (D130756, p. 21).

TABLE 1 Summary of Economic Analysis—Los Alamos National Laboratories

Cost Category	Case 1 100 scfm Flow Rate Inlet Concentration 50 ppm[a]	Case 2 100 scfm Flow Rate Inlet Concentration 1000 ppm	Case 3 500 scfm Flow Rate Inlet Concentration 1000 ppm[b]
Bare equipment costs	$31,473	$70,780	$353,898
Total equipment costs	$33,991	$76,442	$382,209
Total capital cost	$78,034	$132,475	$527,235
Total capital required	$144,362	$245,671	$975,385
Labor	$16,026	$16,026	$16,026
Maintenance	$6.243	$10,624	$42,179
Annual energy cost	$20,832	$47,712	$237,888
Annual capital	$3,651	$8,210	$41,052
Annual VOC recovery lb/yr	1,092(495 kg)	21,840(9,910 kg)	109,200(49,530 kg)
Unit cost $/lb 10-year operation	$56($240/kg)	$5($11/kg)	$4($9/kg)

Source: Adapted from D130756.

[a] 100 scfm = 2.83 standard cubic meters per minute (scmm).

[b] 500 scfm = 14.2 scmm; contaminant waste stream assumed to contain 70% perchloroethylene, 30% trichloroethylene.

In 1997, LANL and SEMATECH conducted an evaluation of SDP technology as a method of abating emissions from lithotrack etching operations in semiconductor manufacturing at the point of use (POU). It is believed that the development of POU abatement technologies would allow for greater flexibility, reduce operating expenses, and provide a higher level of emissions control. Following the evaluation, a cost of ownership estimate was performed. For an influent stream containing 50 ppm propylene glycol monoethyl ether acetate (PGMEA) with a target destruction removal efficiency of 99%, the cost of ownership was $3/lb of VOCs destroyed (D177575, p. 38).

The costs of the SDP system per 1000 standard cubic feet per minute (scfm) were $33,300 as compared to $22,000 for typical end of pipe uses. The study concluded that while replacing end of pipe systems with SDP systems is not recommended, SDP could easily be installed in niche circumstances for POU control of VOCs from lithotrack tools (D177575, p. 9). The document contains a complete breakdown of the factors used to develop this estimate.

Information Sources

D12104Q, Cummings and Booth, 1996
D130756, Cummings and Booth, excerpts only, 1996
D13140Y, U.S. DOE, web page
D13528E, Evans et al., 1993
D177575, Coogan and Jassal, 1997

T0371

High Voltage Environmental Applications, Inc.

High-Energy Electron Beam Irradiation

Abstract
High Voltage Environmental Applications (HVEA), Inc., has developed a high-energy electron beam irradiation process used for the destruction of organic contaminants in groundwater, drinking water, and slurried sediments, soils, and sludges. The technology uses a 1.5-million-volt, 50-mA electron accelerator to create oxidizing and reducing ions in aqueous solutions. These ions act to convert organic compounds into carbon dioxide, water, and salts. The technology has been demonstrated at full-scale level and is commercially available.

HVEA lists the following advantages of the high-energy electron beam process:

- The process is nonselective in the destruction of organic compounds; both strongly oxidizing and strongly reducing compounds are formed at the same time and at the same concentration.
- Reactions produced by the beam occur in less than a second.
- The process is temperature independent and pH independent in range of 3 to 11.
- The process can treat aqueous streams, as well as slurried sludges, soils, and sediments.
- The process produces no organic sludges or air emissions; inorganic precipitates may be formed.
- The process can be used as a pretreatment for bioremediation, breaking apart complex organic compounds to facilitate microbiological degradation.

According to a review by the U.S. Department of Energy (DOE) in 1997, electron beam technology is not feasible for the destruction of organic solids in any form, with the possible exception of biological materials. Solid waste sludges, soil, and debris are impractical

to treat with this technology. Factors that affect removal efficiency of contaminants include applied radiation dose, carbonate alkalinity, carbonate/bicarbonate ion speciation, water quality (the presence of radical scavengers), contaminant concentration, and the specific contaminant treated. Metals present in a reduced state may be oxidized to a more toxic form (e.g., trivalent chromium oxidized to hexavalent chromium), and oxidized metals may form precipitates. For high concentrations of waste, recirculation may be required to meet cleanup goals.

Technology Cost

In 1991, HVEA estimated that the costs associated with the use of a high-energy electron beam system range from \$2.50 per 1000 gal for a system with a flow rate of 160 gal/min to \$0.25 per 1000 gal for a system with a flow rate of 2100 gal/min. Based on a treatment facility constructed in Miami, Florida, installation of a permanent electron beam system is estimated to be \$1.85 million. Support facilities are estimated to cost \$0.5 million. The hourly operating expenses associated with electron beam processing are \$20 for operator costs, \$10.50 for power, \$2.50 for water, and \$8 for maintenance. No indirect costs such as supervision, overhead, etc., are included in this estimate. According to HVEA, the estimate is similar to costs for an ultraviolet oxidation process and cheaper than wet oxidation technology. HVEA also states that costs for a transportable system will be significantly higher due to transportation costs, maintenance requirements, and shorter useful facility lives (D12589N).

In 1994, treatment costs at the U.S. DOE's Savannah River Site (SRS) were between \$4 and \$6 per 1000 gal. However, a small-scale system was used, and some problems were encountered. This project was initiated as part of the EPA's Superfund Innovative Technology Evaluation (SITE) demonstration program. The Innovative Technology Report of the Demonstration contains a detailed economic analysis of the high-energy electron beam system. This evaluation can be found in D186565, pages 36 through 48.

In 1996, HVEA estimated that actual costs for the high-energy electron beam process will range from \$1 to \$2 per 1000 gal of contaminated groundwater. HVEA also states that costs could be as high as \$400 per 1000 gal of high-strength industrial wastewater or slurried sediment (D13346A, p. 29).

In 1997, the U.S. DOE conducted a review of nonflame remediation technologies for the destruction of hazardous organic waste. The report stated that several factors had restricted the use of high-energy electron beam technology: its size, perceived cost, and a lack of understanding in the environmental community. Although a major initial investment is required and additional costs of housing the fixed system will be incurred, the life-cycle costs may be low over a 20-year operating period. The initial capital cost of a direct current 2.5-megaelectronvolt (MeV) system is estimated to range between \$1 million and \$1.5 million. However, direct current accelerators have been used in industry for years and are considered reliable, suggesting low maintenance costs (D18441S, p. A-21).

In collaboration with Haley & Aldrich, Inc., HVEA tested the high-energy electron beam technology's ability to treat methyl tertbutyl ether (MTBE). The technology, known as electron beam (or E-beam) for this application, has treated MTBE in waste streams to concentrations below U.S. EPA maximum contaminant levels. This level of treatment can be attained at a cost of \$1.00 to \$1.25 per 1000 gal of water treated (D22179E, p. 1).

Information Sources

D12589N, Kurucz et al., 1991

D13346A, Industrial Wastewater, 1996

D18441S, Schwinkendorf et al., 1997

D186565, U.S. EPA, 1997

D22179E, Environmental Business Association of New York State, undated

T0372

Hi-Point Industries, Ltd.

Oclansorb

Abstract
Oclansorb is an absorbent made from peat moss. It is designed to absorb hydrocarbon contaminants from hard surfaces or water. Oclansorb can be used as a dry powder and is also used as the active component in socks, booms, and spill kits. Oclansorb has been available in the United States for over 12 years and is patented to Hi-Point Industries, Newfoundland. The product is available in the United States from licensed Oclansorb distributors.

The vendor lists the following advantages of Oclansorb technology:

- More cost effective than other absorbants.
- More efficient than other absorbents.
- Reduces up to 90% of combustible vapors upon application due to its high vapor suppression capacity.
- Reduces man-hours required for cleanup.
- Hydrocarbons are taken into the Oclansorb material, they do not merely attach to the outer surface of the product.

Unless the absorbent is used in a landfarming application, the absorbent and recovered contaminants may require disposal as hazardous waste.

Technology Cost
No available information.

T0373

Horizontal Drilling/Horizontal Wells — General

Abstract
Horizontal drilling techniques were originally developed in the petroleum industry. In the late 1980s, private industry and the federal government began development of horizontal drilling for environmental applications.

Several vendors offer proprietary horizontal technologies. It was reported in January 2002 that environmental horizontal wells have been installed in more than 35 states in the United States More than 250 environmental horizontal wells have been installed in Colorado. Other states with more than 30 horizontal wells include California, Florida, Louisiana, Michigan, New York, North Carolina, Ohio, Oklahoma, and Washington.

Horizontal drilling is most commonly used to emplace horizontal wells. A vendor of horizontal drilling technology states that horizontal wells offer three demonstrated design advantages over vertical wells:

- Horizontal wells allow for recovery in circumstances of limited overlying access.
- The technique maximizes well surface area.
- It is possible to orient well screens in closer proximity to the bulk of contamination.

The effectiveness of both horizontal and vertical wells are limited in low transmissivity zones. Well installation depths can be limited. The installation of deep horizontal wells may be cost

prohibitive. Horizontal wells are at a geometric disadvantage in areas where the contaminated zones cover a very small area or are vertically oriented. Horizontal drilling is not applicable to light non-aqueous-phase liquid (LNAPL) extraction in areas with high water table fluctuations. Also the vertical capture zone in a horizontal well may be limited by the vertical hydraulic conductivity, which is usually less than the horizontal conductivity.

Technology Cost

Horizontal drilling and well installation costs are quite variable, depending on the depth of installation, site geology, site-specific institutional requirements, well design, well materials, etc. (D18187X). The type of drilling fluid used and the size of the drilling team will also influence installation costs. The U.S. Department of Energy (DOE) provided a rough estimate that the installation of one horizontal well cost about the same as five vertical wells. However, the operation and maintenance (O & M) costs for a horizontal well were estimated at one-third the cost of five vertical wells (D21201R, p. 1). Studies have shown that horizontal wells, after one year of operation, are more economical than vertical well systems (D18187X).

According to data provided by the DOE in 1995, when horizontal wells are installed at depths greater than 40 to 50 ft, river crossing drilling techniques are typically used. The cost associated with drilling is approximately $200 per foot. At depths less than 40 to 50 ft, drilling techniques used by utility industry compactors or smaller river-crossing rigs are used. Costs for these systems can be as low as $50/ft (D168585, p. 10).

The DOE states that horizontal well installation costs have steadily decreased in recent years due to technical improvements and increased experience of drilling companies (D168585, p. 10). Most horizontal wells are installed at private industry sites, so performance information and cost data are not commonly available (D22909O, p. 2).

The economics of a horizontal well system are enhanced when its application allows operating businesses to remain open during remediation efforts. The use of 25,000 linear feet of horizontal wells beneath runways at New York's JFK Airport, allowed remediation to take place without disrupting takeoff schedules (D20792L, p. 3).

According to researchers, horizontal wells are especially cost effective at low-permeability sites where numerous vertical wells would be required. For example, at Williams Air Force Base in Arizona, a single horizontal well was estimated to have replaced 80 vertical wells (D20792L, p. 5).

In 1996, the Colorado Center for Environmental Management published data from vendors of horizontal well technologies. A table listing the name of the contractor, the location and date of sites drilled, with pertinent information such as site geology, the purpose of the well, the number of wells drilled, the type of borehole, the length and depth of the wells, the well materials, and the cost of the project is listed in D168574, page 4-1. Cost information was not given for each site, but costs listed for horizontal well drilling ranged from $15,100 for four shallow wells drilled in silty sand to $1.2 million for eight wells drilled in lime soil at a depth of 40 ft and a length of 800 ft (D168574, pp. 4-1–4–14).

In 1996, a field demonstration of horizontal recirculation wells was conducted at the X-701B site of the Portsmouth Gaseous Diffusion Plant in Piketon, Ohio. Using directional drilling methods, two horizontal wells 234 ft long were installed to a depth of 32 ft. Design and construction costs were estimated to be $1.43 million (D188709, p. 16).

In 1993, ex situ soil vapor extraction using nondrilled horizontal wells was used at a contaminated site in Douglasville, Georgia. The U.S. Environmental Protection Agency (EPA) reported that the total cost of the remediation project was $2.2 million. Treatment costs were estimated to be $413/yd^3 of soil treated (D20793M, pp. 20, 21). Treatment costs are summarized in Table 1.

Information Sources

D168574, Colorado Center for Environmental Management, 1996

D188709, U.S. EPA, 1998

TABLE 1 Cost Estimate for Ex Situ Soil Vapor Extraction (SVE) Project

Cost Item	Estimated Cost in Dollars
Costs Encountered before the Initiation of Treatment	
Monitoring, sampling, testing, and analysis	260,000
Site activities—excavation and soil preparation (screening)	390,000
Air pollution/gas collection and control enclosure, air handling system, and part of the incinerator	650,000
Total	1,300,000
Costs Encountered During Treatment	
Operation (short-term; up to 3 years)	130,000
Cost of ownership [soil vapor extraction (SVE) system, part of incinerator]	530,000
Total	660,000
Costs Encountered After Treatment Completed	
Disposal (commercial)	130,000
Site restoration	22,000
Demobilization	68,000
Total	220,000

Source: Adapted from D20793M.

D18187X, Kaback, 1997
D20793M, U.S. EPA, 1995
D20792L, U.S. DOE, 1997
D22909O, GWRTAC, 2002
D21201R, U.S. EPA, 2000

T0374

Horizontal Subsurface Systems, Inc.

Linear Containment Remediation System

Abstract
The linear containment remediation system (LCRS) is an in situ technology designed to treat soil contaminated with dissolved and free-phase hydrocarbons. The system consists of trenched horizontal wells and the proprietary trenching equipment used to install them. The wells are often used as injection or recovery wells but can also be paired with soil flushing, soil vapor extraction (SVE), air sparging, or bioremediation. Trenching and delivery equipment digs a trench, lays perforated pipe, and covers the trench with backfill in one step. The system can be installed adjacent to or directly through plumes of contamination, increasing recovery efficiency over traditional vertical well installations.

The technology is patented and has been used during full-scale remediation efforts. LCRS is commercially available through Horizontal Subsurface Systems, Inc.

According to the vendor, the LCRS system has several advantages:

- Recovers contaminants at higher concentrations that conventional, vertical recovery wells.
- Accurately installs horizontal wells to a specified depth.

- Reduces remediation time.
- Provides more focused contact between contaminants and the extraction well.

Sites with low depth to bedrock are not suitable for LCRS technology. The technology cannot be installed directly under a building or landfill. In addition, the size of the trenching machine may limit its use in urban areas containing underground pipelines, wires, and utility cables. The trenching machine requires an area that is at least 4 m wide to function. Currently the maximum depth capacity of the equipment is approximately 32 ft, although benching techniques have provided successful installations to 50 ft below ground surface.

Technology Cost

The vendor estimated that the treatment costs associated with using LCRS as injection or extraction wells range from $100 to $250/ft. The estimated costs for future projects containing an air sparging component range $250 to $400/ft (1996 dollars). Factors impacting the costs include length of the well and well screen, moisture content of the soil, depth to groundwater, characteristics of the soil, initial contaminant concentration, target contaminant concentration, transportation distance, depth of contamination, site preparation, depth to groundwater, and waste handling/preprocessing (D10075U, p. 8; D10074T, p. 36).

According to the vendor, an LCRS costs 50% less than a horizontal well bore system and 70% less than a vertical well system. For example, the vendor claims that a site in Charlotte, North Carolina, contaminated with 300,000 gal of hydrocarbons was treated using LCRS and SVE. The total costs for both systems were $575,000. The cost for the LCRS system was estimated between $300,000 and $350,000. These costs were significantly lower than the initial estimate of $1,000,000 to remediate the site using vertical wells (D140465; D14459M, p. 7; D22540B, p. 13).

Dewatering of the site prior to well installation is not necessary. This can allow for cost savings over traditional vertical well installations (D140465). In addition, the wells can be installed at predetermined levels to minimize the amount of groundwater removal and reduce the associated treatment costs. Reduced removal volumes occur when the well passes through the highest concentrations of contaminants (D18293Y, p. 1).

Information Sources

D10075U, VISITT, 1996

D10074T, VISITT, 1996

D140465, Farrell, 1993

D14459M, Horizontal Technologies, Inc., 1995

D18292X, Horizontal Technologies, Inc., 1998

D18293Y, Horizontal Technologies, Inc., 1998

D22540B, Horizontal Subsurface Systems, Inc., 2001

T0375

Horizontal Subsurface Systems, Inc.

Polywall Barrier System

Abstract

The polywall barrier system is a containment technology that consists of an impermeable geomembrane and specially designed emplacement equipment. The geomembrane is a continuous sheet of high-density polyethylene (HDPE) with a thickness ranging from 40 to 100 mil. The HDPE is installed vertically to depths of more than 30 ft using a specialized trenching machine. The machine cuts through the subsurface, installs the barrier wall, and backfills the hole in a single pass.

The polywall barrier system was developed by Horizontal Technologies, Inc. (HTI), of Matlacha, Florida. The first polywall barrier system was completed in 1993. Since that time, the technology has been demonstrated at more than 10 other sites and used in full-scale remediation applications. The polywall barrier technology is currently commercially available through Horizontal Subsurface Systems, Inc.

According to the vendor, the polywall barrier system has several advantages:

- Installs rapidly.
- Adjusts to irregular geometries and topographies.
- Has a lower cost than conventional technologies.
- Generates a minimum amount of trenching spoils.

The polywall barrier system is not a treatment technology. The long-term durability of HDPE is not known.

Technology Cost

In general, the cost of HDPE similar to the type used in the polywall barrier system ranges from \$10 to \$30/ft^2. Installation costs using a trenching machine usually range from \$2 to \$5/ft^2 (D20300P, p. 25).

Information Source

D20300P, Pearlman, 1999

T0376

Horner & Company

Max Bac

Abstract

Max Bac® is an in situ microbial nutrient supplement technology that is used to enhance the biodegradation of wastes in an aqueous medium, soil, sediment, or sludge. According to the vendor, this technology has been incorporated into various pilot- and full-scale land treatments; composting and biopile applications, ocean beach remediation, activated sludge and trickling filter systems, in situ projects, and in packed-bed columns for remediation of airstreams. The vendor also indicates that this technology has been used in the remediation of gasoline, diesel fuel, crude oil, pesticides, creosote, and pentachlorophenol.

The vendor claims the following advantages for this technology:

- Increases the natural biodegradation rate and decreases cleanup time.
- Limits the potential for nitrate and phosphate leaching into surface and groundwaters.
- Limits the potential for nutrient-matrix precipitation reactions.
- Reduces requirement for costly nutrient reapplications.

Technology Cost

According to the vendor, the cost of treating 1 yd^3 of soil or sediment with Max Bac is \$1.00 to \$4.00. Typical product application rates are between 1 and 3 lb/yd^3 of soil. This cost is highly dependent on the nutrient release rate and freight costs (D16076J, p. 3, D17235K, p. 2). Specific prices are given in Table 1.

TABLE 1 Prices of MaxBac and Customblen® Nutrients for Bioremediation

Customblen Number	Analysis (NPK)	Price per Unit	Price per Pound
CB 94–203 (50# bag)	23-2-8 (3–4 month)	\$54.00	\$1.08
CB 94–204 (50# bag)	23-2-8 (6–7 month)	\$56.00	\$1.12
CB 94–441 (25# bag)	31-5-7 (water soluble)	\$25.00	\$1.00

Source: D17235K.

Information Sources

D16076J, Horner & Co., 1994
D17235K, Horner & Co., 1998

T0377

Horsehead Resource Development Company, Inc.

Flame Reactor

Abstract
The Horsehead Resource Development Company, Inc. (HRD) flame reactor technology is a patented high-temperature metal recovery (HTMR) technology used for the treatment of wastes and residues containing toxic levels of leachable metals. The HRD flame reactor has a combustion zone temperature greater than 2000°C that either destroys or removes the organic compounds. Metal constituents can be recovered in a concentrated form that is suitable for recycling, thereby reducing treatment costs. Nonrecoverable metals are concentrated in a nonleachable, effluent slag that meets Environmental Protection Agency (EPA) Resource Conservation and Recovery Act (RCRA) criteria for nonhazardous waste. This allows the slag to be used either as aggregate or disposed of in a permitted, nonhazardous waste landfill. Air emissions from the process are controlled with the addition of standard emission control hardware.

The HRD flame reactor technology is suitable for the treatment and recovery of metals from sludges, slags, and metal-contaminated soils. The HRD technology treats metal-containing industrial residues, granular solids, soil, flue dusts, slag, and sludges that contain heavy metals. HRD claims that the flame reactor technology has successfully treated the following wastes: electric arc furnace dust, lead blast furnace slag, soil, iron residues, primary copper flue dust, lead smelter nickel matte, zinc plant leach residues and purification residues, brass mill dusts and fumes, and electroplating sludges.

Among the advantages of the HRD technology are:

- Flame reactor immobilizes metals into a nonhazardous, vitrified slag even at low metal concentrations.
- Reduces mobility of metals.
- Reduces volume of waste requiring land disposal.
- Operates over a range of operating parameters.
- Utilizes a variety of fuels.
- Short startup and shutdown periods.

In general, the system requires that wastes contain less than 5% total moisture and with a particle size less than 200 mesh. Wastes must be transported to a stationary HRD facility for treatment. The HRD flame reactor system cannot treat mercury-containing wastes.

Technology Cost
An economic analysis of the HRD flame reactor technology was performed by the U.S. EPA using 12 separate cost categories. Based on the assumptions made in the economic analysis, the estimated cost for treating secondary lead soda slag (SLS) ranges from $208 to $932 per ton.

The cost depends on the quantity of waste to be treated and the location of the site relative to the HRD treatment facility (D104596, pp. 2–3). Table 1 contains estimated costs associated with HRD flame reactor systems based on the following 12 EPA cost categories (D104596, p. 20):

- Site preparation
- Permitting and regulatory requirements
- Capital equipment
- Startup
- Labor
- Consumables
- Utilities
- Effluent monitoring
- Shipping, handling, and transporting residuals
- Analytical testing
- Equipment repair and replacement
- Site demobilization

For the EPA Superfund Innovative Technology Evaluation (SITE) program demonstration, the HRD flame reactor system processed SLS from the National Smelting and Refining Company (NSR) Superfund site in Atlanta, Georgia, at a cost of $932 per ton (D104596, p. 3). This cost estimate is based on treating less than 24 tons of processed rotary kiln SLS. EPA has estimated cost to be $208 per ton for a 50,000 ton per year processing system that includes a waste pretreatment system for more efficient waste processing (D104596, p. 22).

Comparative cost data in a 1994 American Academy of Environmental Engineers Report indicate HRD flame reactor treatment costs ranging from $215 per ton for SLS to $228 per ton for contaminated soil (D14632H, p. 2.14)

Information Sources

D104596, EPA SITE Applications Analysis Report, May 1992

D14632H, American Academy of Environmental Engineers Report, 1994.

TABLE 1 Estimated Costs Associated with HRD Flame Reactors

Operating Scenario	SITE Test	Commercial Operations (scenarios 2–6)				
Scenario number	1	2	3	4	5	6
Plant	HRD Monaca facility	HRD Monaca facility	On-site	HRD Monaca facility	On-site	On-site
Capital ($million)	2.5	2.5	3.1	4.5	6.0	10.4
Annual capacity (tons)	6,700	6,700	6,700	13,400	20,000	50,000
	Estimated costs per ton of waste treated (1991 $)					
Total cost per ton waste	$932	$458	$448	$350	$263	$208

Source: Adapted from EPA SITE Applications and Analysis Report, 1992 (D104596, p. 20).

T0378

HPT Research, Inc.

Ionic State Modification (ISM) Process for the Treatment of Acid Mine Drainage

Abstract
HPT Research, Inc., has developed the ionic state modification (ISM) process for the treatment of acid mine drainage (AMD). ISM is an ex situ treatment technology that uses magnets, electricity, and proprietary chemical to precipitate heavy metals, remove sulfate ions, and neutralize acidity from AMD and industrial wastewaters. The end products of the process are a metal hydroxide sludge, a calcium sulfate sludge, and treated liquid effluent. The vendor claims that the metal hydroxide sludge may have some value as an ore, the calcium sulfate may be used as an agricultural additive to soils, and the liquid effluent is free of metal contamination and has low sulfate concentrations.

HPT Research, Inc., developed the ISM process to remove heavy metals, sulfate ions, and acidity from AMD. According to the vendor, HPT Research, Inc., has conducted research and development and third-party testing with the U.S. Department of Energy's (DOE's) Lawrence Livermore National Laboratory, California State University Fresno, and the U.S. Environmental Protection Agency (EPA). This technology has been demonstrated on a bench scale. The process and proprietary chemical additives are patented. HPT Research, Inc., is seeking opportunities to demonstrate the ISM process on a pilot scale.

According to the vendor, the ISM process for the treatment of AMD has several advantages:

- Extracts heavy metals while producing a relatively small volume of metal hydroxide sludge.
- Produces an anhydrous calcium sulfate that is void of metal contamination and has a potential value as an agricultural soil amendment.
- Has the capability of reducing sulfates in the final effluent to extremely low levels (parts per million).
- Produces a final effluent that will meet discharge limits.
- Generates the majority of the chemical additives during stage II.

All information is from the vendor and has not been independently verified.

Technology Cost
According to the vendor, the ISM process reduces the cost of chemical additives because stage II generates the primary additive for stage I. The metal hydroxide produced in stage I of the process may have a residual value as a recyclable material. The vendor states that although this value is not great, it may help to offset freight disposal costs (D208048, p. 1; D208037, p. 3).

Information Sources

D208037, HPT Research, Inc., undated
D208048, HPT Research, Inc., undated

T0379

Hrubetz Environmental Services, Inc.

HRUBOUT Process, In Situ

Abstract
The HRUBOUT® technology is a mobile thermal desorption process that can be used in situ or ex situ. HRUBOUT is designed to remediate soils contaminated with volatile organic compounds

(VOCs) and semivolatile organic compounds (SVOCs). This technology is also available in a containerized process. During in situ applications, heated compressed air is injected into the soil below the contaminated zone. The heated air evaporates soil moisture and removes volatile and semivolatile contaminants. The vapor is collected and transferred to a thermal oxidizer for destruction. The ex situ HRUBOUT process is discussed in RIMS2000 technology summary number T0380. HRUBOUT can treat soils contaminated with halogenated or nonhalogenated VOCs and SVOCs, including gasoline, diesel oil, jet fuel, heating oil, chemical solvents, and other hydrocarbon compounds.

Four patents pertaining to the HRUBOUT technology have been issued. The initial patent for the in situ process was granted in 1991. The in situ HRUBOUT process was demonstrated in the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program in January and February 1993 at Kelly Air Force Base in San Antonio, Texas. This technology is commercially available.

According to the vendor, some advantages of the in situ HRUBOUT technology are that it:

- Reduces the risks, costs, and effort associated with excavation and ex situ remediation technologies.
- Allows for the treatment of a variety of VOCs and SVOCs.
- Is mobile.
- Destroys 99.5% of the recovered contaminants.

The duration of the remediation is dependent on the soil type, water content, and the nature of the contaminants. The HRUBOUT process cannot remove metals from soils. Polychlorinated biphenyls (PCBs) cannot be totally removed. The in situ HRUBOUT process is designed for removing contaminants from the vadose zone, (i.e., the zone between the surface and the water table). Low permeability lowers system effectiveness and raises remediation costs. Soils with variable permeabilities may cause uneven delivery of air to contaminants. VOC removal rates may be reduced by high organic content in the soil because soil organics have a high VOC-sorption capacity.

Technology Cost

In 1991, the vendor estimated the cost for the in situ HRUBOUT process at \$50 to \$90/yd^3 of soil treated, based on continuous operation (D14096F, p. 36). Factors that have a significant effect on unit price in order of importance include the following:

- Moisture content of soil
- Amount of debris with soil or waste
- Utility/fuel rates
- Characteristics of soil
- Labor rates
- Target contaminant concentrations
- Site preparation
- Initial soil concentration (D141151, p. 33).

The in situ HRUBOUT process was used to treat a 10-ft-by-20-ft area to a depth of 20 ft. Soil at the site was contaminated with total petroleum hydrocarbons (TPH). According to the vendor, the cost of the remediation activities was approximately \$75/yd^3 of contaminated soil (D10050L, p. 15).

Information Sources

D10050L, VISITT 4.0, undated

D14096F, Hrubetz, Environmental Waste Management Magazine, 1991, p. 36

D141151, VISITT 5.0 (excerpts), 1996

T0380

Hrubetz Environmental Services, Inc.

HRUBOUT Process, Ex Situ

Abstract

The HRUBOUT® process is a mobile in situ or ex situ thermal desorption process designed to remediate soils contaminated with volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs). For the ex situ process, excavated soil is treated in a soil pile or in a specially designed container. Heated compressed air is injected into the soil, evaporating soil moisture and removing volatile and semivolatile contaminants. Heavier hydrocarbons are oxidized as the soil temperature is increased to higher levels over an extended period of time. The vapor is collected and transferred to a thermal oxidizer (incinerator) for destruction.

This technology can treat soils contaminated with halogenated or nonhalogenated VOCs and SVOCs, including gasoline, diesel oil, jet fuel, heating oil, chemical solvents, and other hydrocarbon compounds. The HRUBOUT process is not applicable for removal of metals.

Four patents pertaining to the technology have been issued. The ex situ HRUBOUT process has been applied at several sites. This technology is commercially available. The HRUBOUT process has been approved by the Texas Natural Resources Commission.

The HRUBOUT process may also be applied as an in situ technology for excavated soils (see Hrubetz Environmental Services, Inc., HRUBOUT Process, In Situ, T0379).

Technology Cost

In 1991, the cost of the ex situ technology was estimated by the vendor to run approximately \$40 to \$50/yd^3 of soil treated (D14096F, p. 36). This estimate does not include costs for soil analysis or dirt work (i.e., soil excavation or placement after treatment).

Factors that have a significant effect on unit price in order of importance include the following:

- Moisture content of soil
- Amount of debris with soil or waste
- Utility/fuel rates
- Characteristics of soil
- Labor rates
- Target contaminant concentrations
- Site preparation
- Initial soil concentration (D141151, p. 33)

The vendor has provided estimates of the operating costs for the containerized process using either the dump container or the auger container. Estimates for both purchase and lease scenarios are presented in Table 1. The cost of propane (to heat the soil and to operate the thermal oxidizer) is the largest single operating cost for the HRUBOUT process. Estimated

TABLE 1 Estimated Operating Costs for HRUBOUT Process Using Dump or Auger Container

Container and Scenario	Operating Cost (per yd^3)[a]	Operating Cost (per ton)[a]	Container Purchase or Lease Cost
Dump container, purchase scenario[b]	$12.95	$8.20	$200,000
Dump container, lease scenario[c]	$11.05	$7.00	$1,200 per day
Auger container, purchase scenario[b]	$13.61	$8.62	$250,000
Auger container, lease scenario[c]	$11.05	$7.00	$1,200 per day
10-ton mobile unit[d]	(see container operating costs)	(see container operating costs)	250,000 purchase or $1,000 per day, to lease[e]
5-ton mobile unit[d]	(see container operating costs)	(see container operating costs)	130,000 purchase or $700 per day, to lease[e]

Source: Hrubetz Environmental Services, Inc., Vendor information, 1996 (D12919L).
[a]Costs are estimated based on 8 hours per load; a load comprises approximately 38 yd^3 or 60 tons.
[b]Estimated operating costs include electricity, propane, labor, overhead, insurance, and depreciation (3 years).
[c]Estimated operating costs include electricity, propane, labor, and overhead.
[d]The mobile unit consisting of the thermal oxidizer, air heating unit, blowers, and other equipment is used in conjunction with the portable 25-yd^3 container provided by Hrubetz (personal communication: Michael Hrubetz, Hrubetz Environmental Services, Inc., December 1996).
[e]Mobile unit costs are from Hrubetz Environmental Services, Inc., vendor information, 1996 (D14097G).

propane costs (1996 dollars) comprise about 39 to 47% of operating costs, depending on the scenario (D12919L).

Information Sources

D12919L, Hrubetz Environmental Services, Inc., Container Cost information, 1996

D14096F, Hrubetz, Environmental Waste Management Magazine, 1991

D14097G, Hrubetz Environmental Services, Inc., vendor information, 1996

D141151, U.S. EPA, VISITT 5.0 (excerpts), 1996

T0381

Hughes Environmental Systems, Inc.

In Situ Steam-Enhanced Recovery Process

Abstract
The steam-enhanced recovery process (SERP) is an in situ technology designed to remove and treat volatile and semivolatile organic compounds (VOCs and SVOCs) in contaminated soils by using steam injection and vacuum extraction. The technology is based on the idea that added heat (thermal enhancement) increases the volatility and mobility of SVOCs and VOCs and thus facilitates the extraction of soil contaminants. The process works by injecting high-quality steam

through injection wells constructed to a depth at or below the contamination at a site. Additional extraction wells are operated under a vacuum to create a pressure gradient to draw the liquids, vapor, and contaminants through the soil. Liquid and vapor streams removed by the extraction wells are then treated by an above-ground liquid and vapor treatment system.

SERP is not appropriate for treatment in nonpermeable or low permeability strata such as rock or thick clay layers. Fractured rock formations and geological structures with high permeability "tunnels" within them would cause preferential steam flow and would not allow most areas of soil to be appropriately treated by the technology.

The less volatile the contaminants, the more difficult they are to remove from the soil. Treatment of less volatile contaminants would mean longer treatment times, less complete removal efficiencies, and higher treatment costs overall. Shallow contamination, or very narrow depth intervals of contamination, would not be appropriate to treat due to the difficulty of controlling the steam zone to a narrow range and the high costs per cubic yard based on the area of the site. Capital and mobilization costs for the technology are high enough that only large volumes of soil are economical for treatment.

A key advantage of this technology is that little excavation is required to treat the soil. Since the soil is treated in place, the waste is not subject to any land disposal restrictions that might be applicable if excavation were required. Also, a unique feature of this technology is that it can treat contaminated soils under and around existing structures.

The vendor for this technology is no longer in the environmental cleanup business. However, this technology is available from a number of vendors, and a summary of the technology in general is available in T0407, In Situ Steam Extraction—General.

Technology Cost

In 1991, the SERP was demonstrated at the Rainbow Disposal site in Huntington Beach, California, under the Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) program. Total costs for the remediation at the site was approximately \$4,400,000. This cost does not include legal fees. The total amount of soil that was considered to have undergone treatment was 95,000 yd^3, which includes the volume of soil within the treatment perimeter between the depths of 20 and 40 ft. This yields a treatment cost of \$43/yd^3 (D15382M, p. 7).

Two additional cost estimates were prepared based on ideal conditions (no downtime or a 100% online factor) and on conditions expected to be typical of a treatment process of this type (using an online factor of 75%). Total costs for the ideal case were estimated to be about \$2,800,000 or \$29/yd^3 and for the typical case costs were estimated to be \$3,400,000 or \$36/yd^3 (D15382M, p. 7).

Costs for the use of SERP are highly site specific since the equipment and operating techniques are tailored to the individual characteristics of the site. Factors that would tend to increase treatment time, such as less volatile contamination, larger site area, or less permeable soils, would have the most significant effect on the costs for the use of the technology (D15382M, p. 7).

Information Source

D15382M, U.S. EPA, 1995

T0382

University of Idaho/Humboldt State University

Chitosan Derivatives

Abstract

Chitosan, a polymer derived from shellfish, has been chemically altered to enhance its metal-binding properties. Chitosan derivatives have potential for treating wastewater contaminated with

metals, such as that generated by mines, industrial operations, metal plating, and fabrication. Since chitosan binds uranium, these new derivatives may also bind uranium, but the developer claims that experimental work will need to be done in this area.

Chitosan is a polymer with metal-binding properties that is derived from naturally occurring chitin. Research has been conducted on the potential use of chitosan in hazardous waste remediation. While chitosan does bind transition metals, it favors iron, a nonhazardous metal, which competes and interferes with chitosan's binding of toxic metals. Copper also tends to be highly bound, while the amount of cadmium and lead removed is lower. The technology is still undergoing testing and is not yet commercially available.

Technology Cost
No available information.

T0383

Huntington Environmental Systems

Econ-Abator Catalytic Oxidation System

Abstract
The Econ-Abator® system is a fluidized-bed catalytic oxidation system. Catalytic fluidized beds allow for destruction of volatile organic compounds (VOCs) at lower temperatures than conventional oxidation systems (typically 500 to 750°F). The technology uses a proprietary catalyst consisting of an aluminum oxide sphere impregnated with chromium oxide.

The technology has been used in many industrial applications, including the treatment of emissions of VOCs, chlorinated VOCs, odor precursors, nitrogen oxides, and ammonia. The technology can be integrated into remediation systems for soil and groundwater remediation applications. The technology has been applied to commercial sites as a component of in situ pump-and-strip systems and has been used as a part of in situ soil venting systems. The technology is commercially available.

According to the vendor, the technology has the following advantages:

- Minimizes fuel costs.
- Uses a catalyst that does not foul, and is not poisoned by, metals or halogens.
- Operates at low inlet temperatures.
- Uses the self-cleaning action of the fluidized bed to keep catalyst activity high.
- Allows for catalyst to be added to the system while still in operation.
- Reduces operating costs by offering heat recovery modules.

The decomposition of the catalyst beads can cause a secondary air pollution emission consisting of the particulate dust generated by abrasion of the surface of the catalyst. Operating cost for catalyst replacement varies directly with catalyst attrition rate. The system can process waste streams with VOC concentrations of up to 25% of the lower explosive limit (LEL). The proprietary catalyst contains up to 10% chromium, including 4% hexavalent chromium. This could lead to the emission of hexavalent chromium in some applications of the technology.

Technology Cost
In 1994, capital costs for a fluidized-bed oxidation unit were estimated based on data from a demonstration at Wurtsmith Air Force Base in Oscoda, Michigan. The cost estimate included $83,000 for equipment and $15,000 for installation (D14874X, p. 5.4).

Data were obtained from Wurtsmith personnel regarding the quantity of water treated by the air stripper/catalytic oxidation system during the evaluation. The four main component of electrical power consumption were the air stripper blowers, the air stripper water pumps, the incinerator blower, and the air compressor to operate the pneumatic controls. The catalytic oxidation unit and the building auxiliary heat system used natural gas. Using these data and the utility cost data, the utility cost with respect to the quantity of water treated was determined. For the purposes of the case study, the total cost of electricity and natural gas usage was used to determine the utility costs for the oxidation unit, recognizing that this will be a conservative figure. The average utility cost per 1000 gal of water treated was estimated to range from \$0.48 (FY 1989) to \$0.36 (FY 1991) (D17192Q, p. 57).

Information Sources

D14874X, Anderson, 1994
D17192Q, Hylton, 1992

T0384

Hydraulic Fracturing Technology — General

Abstract
Hydraulic fracturing, a drilling technique first used to improve well yields in the petroleum industry, is now being used to improve permeability and promote remediation in soils contaminated with organic compounds. Hydraulic fracturing forms an integrated network of sand-filled fractures in contaminated clays, glacial tills, and other fine-grained sediments. The technology can increase recovery rates in both liquid and soil vapor extraction wells. Hydraulic fracturing can be used in conjunction with treatment technologies such as soil vapor extraction, in situ bioremediation, in situ vitrification, in situ electrokinetics, and pump-and-treat systems.

The technology has been used in full-scale remediation activities and is commercially available through a number of vendors. Vendor-specific hydraulic fracturing technologies featured in RIMS2000 include Golder Associates FracTool technology (T0351); FRX, Inc., Hydraulic Fracturing (T0318); and FOREMOST Solutions, Inc., IronNet and Iron Curtain (T0312).

The following advantages are claimed for hydraulic fracturing technology:

- Increases effective radius of treatment wells; leads to fewer wells required.
- Increases permeability of soil.
- Reduces treatment time.
- Increases removal of contaminants trapped in natural fractures and adjacent soils.
- Allows for remediation alternatives by improving performance of in situ techniques.
- Allows for fractures to be filled with amendments that improve the performance of remediation technologies.
- Potentially reduces capital and operating costs.

The technology does not alter the contamination present and must be used in conjunction with a treatment technology. The maximum effective depth that can be achieved by hydraulic fracturing is dependent on the fracturing fluid viscosity, the pressure applied, the stiffness of the ground, and, in an indirect way, formation permeability. Cemented sediments limit fracturing effectiveness. Ground deformation models are required to quantify the fracture geometry data acquired by surface sensors and monitor the growth of the created fracture. Hydraulic fracturing may cause ground heave, so monitoring is required when hydraulic fracturing is used near structures.

Technology Cost

In a 1993 evaluation of hydraulic fracturing technology performed by the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration program, it was estimated that the capital cost of hydraulic fracturing equipment was approximately $92,900 and the cost of renting the equipment was approximately $1000 per day. Rental, operating, and monitoring costs for creating a fracture range from $950 to $1425, depending on site-specific conditions. Typically two to three fractures are created per well, and four to six fractures can be created in a day. The cost of creating the fracture is not materially affected by the depth of the fracture for depths ranging from 5 to 40 ft below ground surface and is unaffected by the type of soil encountered. One conclusion from the SITE evaluation was that the cost of the technology is small compared to the benefits of enhanced remediation and the reduced number of wells needed to complete the remediation (D10054P, p. iv). A summary of the cost estimate for hydraulic fracturing is included in Table 1.

According to information supplied by one vendor, Golder Applied Technologies (Golder) in 1996, costs for processing wastes using hydraulic fracturing depend on several factors, including site location, nature, type and depth of contaminant, number of fracture wells, and the amount of sand required. The cost per fracture decreases as the number of fractures increase. Golder also expects the cost of fracturing to decrease as further experience is gained with the technology, and project designs improve (D10587D, p. 5).

In 1995, Golder estimated the total cost of hydraulic fracturing and well installation for a project in Regina, Saskatchewan, at $55,000. A total of 96 fractures were installed on site in seven wells, and the estimated amount of soil treated was 6600 metric tons. The cost per fracture was $575, or $17/m^3 (D10587D, p. 5).

For another site in Regina in 1995, a total cost for 11 fractured wells, two soil vapor extraction systems, and operation and maintenance for 6 months was approximately $80,000. This figure did not include vapor treatment since none was required. Golder estimated that, had hydraulic

TABLE 1 Estimated Costs Associated with Hydraulic Fracturing (in 1993 Dollars)[a]

Cost Category	Daily Cost (in dollars)
Site preparation	1000
Permitting and regulatory	5000
Capital equipment rental[b]	1000
Startup	0
Labor	2000
Supply and consumables	1000
Utilities	0
Effluent treatment and disposal	0
Residual waste shipping and handling	0
Analytical and monitoring	700
Maintenance and modifications	0
Demobilization	400
Total one-time costs (permitting and demobilization)	5400
Total daily costs	5700
Estimated cost per fracture (4 to 6 fractures per day)	950–1425

Source: Adapted from D10054P.

[a] Assumptions include a site in the Midwest, suitable roads to the site, and that boreholes have already been drilled.

[b] Capital equipment rentals include equipment trailer, slurry mixer and pump, mixing pumps, tanks, hoses, fracturing lance, wellhead assembly, notching pump and accessories, uplift survey equipment, scale, and miscellaneous tools and hardware.

fracturing not been applied to the site, the hypothetical cost of excavating and disposing of the 6000 yd^3 of contaminated soil at the Regina site would have ranged from \$180,000 to \$360,000 (D13865S, p. 9).

In October, 1997, FRX hydraulic fracturing technology was used to install a Bio-Net system and a permeable treatment barrier at a gasoline station in Lakewood, Colorado. A permeable treatment barrier was installed at the site in 12 days using hydraulic fracturing methods. The project was designed and installed for \$160,000. The passive system is now in the monitoring phase of remediation (D213332, Appendix p. 93).

In 1988, FOREMOST Solutions installed a pilot-scale permeable reactive treatment (PeRT) wall at the U.S. Department of Defense's (DOD's) Maxwell Air Force Base in Montgomery, Alabama. Treatment wall panels were emplaced up to 75 ft below ground surface (bgs) using patented jet-assisted hydraulic fracturing. The project was designed and installed for \$210,000 including the supplies and down-hole materials. Field installation was completed in 14 days (D213332, Appendix p. 74).

Information Sources

D10054P, U.S. EPA, 1993
D10587D, Leach, 1995
D13865S, Frere and Baker, 1995
D213332, Roote, 2000

T0385

Hydriplex, Inc.

HP-80 Solution and Hydrocleaner 20-10 System

Abstract

HP-80 is a soil washing solution that has been used with the Hydrocleaner 20-10, a soil washing machine, to remove hydrocarbon contamination from soil or sludge. Hydriplex is still an existing company; however, the HP-80 solution and Hydrocleaner 20-10 system are not presently commercially available. The Hydriplex HP-80 technology was used in bench-, pilot-, and full-scale field operations. It was also used to increase oil and gas well production and to clean produced oil contaminated with iron sulfide bacteria.

According to the vendor, the HP-80 solution is a modified tetrahedral polymer based on a nontoxic, organic, and biodegradable silicon hydride compound. It functions as a wetting agent, reducing surface tension by 50%. The solution is a complex of silicon and hydrogen, a hydride in an aqueous solution with a polymeric structure. It is amphoteric in nature, capable of acting as an acid and as a base, combining with both acids and bases. It is not an inorganic monomer, like sodium silicate and many other materials originated from silicon. The solution has a high pH but has electrical and general behavioral properties that are typically on the acidic side of the pH scale.

According to the vendor, the HP-80 technology is effective in removing heavy metals and acids from hydrocarbon-contaminated soil; however, these substances cannibalize the HP-80 compound and higher concentrations of the HP-80 are necessary (3 to 5% by volume instead of 1%).

The HP-80 is not suited for radioactive, polychlorinated biphenyls (PCBs), or pesticide contamination.

Technology Cost

According to the vendor, estimated price range per unit of waste treated is \$15 to \$20 per ton. This cost may not reflect all indirect costs, such as excavation, permits, and treatment of residuals. The most important site-specific factors determining cost of remediation are depth of contamination and quantity of waste (D10049S, p. 13).

Information Source

D10049S, VISITT 4.0

T0386

Hydrocarbon Environmental Recovery Systems

Bioremediation Response Advancement Technologies (BRAT)

Abstract
Hydrocarbon Environmental Recovery Systems' bioremediation response advancement technologies (BRAT) are biological remediation products for treatment of organic contaminants in soil or water. According to the vendor this technology has been applied full scale at a number of sites and is commercially available.

The vendor claims that BRAT offers a system that creates a perfect environment for the bacteria and then inoculates the site with thousands of times the amount of microbes already present. After this addition, the natural and added microbes are provided with the proper amounts of nutrients and oxygen to continue the degradation of hydrocarbons. The bacteria and nutrient sources used are BRAT products.

All information was provided by the vendor and has not been independently verified. This technology is only applicable to biodegradable organic contaminants.

Technology Cost
No available information.

T0387

Hydrocarbon Technologies, Inc.

Recycling Oil Pyrolysis and Extraction

Abstract
Hydrocarbon Technologies, Inc., is the vendor of the recycling oil pyrolysis and extraction (ROPE) process for the remediation of petroleum-contaminated materials. The process was originally developed by the Western Research Institute for the thermal extraction of useful products from tar sand. Wastes are fed through a screw reactor and heated in a three-stage process involving retorting, pyrolysis, and fluidized-bed combustion. Light oils are extracted during heating, and heavy oils are recycled. The gas and some of the oil are consumed to supply heat for the process.

ROPE has been demonstrated for its tar sand applications in field-level studies. Western Research Institute claimed that ROPE technology could be applied to oil-contaminated dirt, tires, petroleum bottoms, oil shale, and tar sand and noted that the process could potentially remove volatile metals such as mercury from soils. Hydrocarbon Technologies, Inc., intends to develop the technology only for tire recycling. The ROPE process has not been tested at a commercial level.

Some of the advantages of the ROPE process include:

- Use of on-shelf equipment items.
- Higher oil yields are achieved than are possible with other technologies.

- Operational simplicity and mechanical simplicity.
- Low pressure operation.
- Improved oil quality.
- Flexibility of feedstocks.

Pretreatment is required for ROPE processing. Materials must be reduced in size to particles no greater than one-tenth the diameter of the screw. Processing is continuous. If the system is shut down, the waste must be removed from the screws with the heating system turned off.

Technology Cost
In 1990, Western Research Institute developed plans for a pilot-scale ROPE commercial facility capable of processing 2500 tons/day (2300 metric tons/day) of material. Estimations of processing costs for ROPE processing were made assuming the primary use of the facility will be to process tar sands. Handling costs for ROPE processing of petroleum bottoms were projected at less than \$1/ton, and a \$30/barrel price for recovered oil would provide a 17% return on investment (ROI). If 50% financing was provided, the institute estimated that even a \$25/barrel oil price could afford a 17% ROI. They further claimed that a larger plant would offer economic advantages (D13089C, p. 247).

For ROPE applications to tar sand mining, economic projections were published for capital costs and operating costs. Total capital costs were estimated at \$53,336,000 and annual operating costs were estimated at \$9,683,000. For the estimation of capital costs, direct field cost was estimated at \$35,558,000. Other capital costs were based on percentages of that estimate. These cost estimates were based on mid-1989 dollars (D13089C, pp. 242–243).

In October, 1996, ROPE technology was acquired by Hydrocarbon Technologies, Inc., of Lawrenceville, New Jersey (Alfred Comolli, Hydrocarbon Technologies, Inc., personal communication, 1996).

Information Source

D13089C, Marchant et al., 1990

T0388

Hydrogen Peroxide, In Situ Bioremediation — General

Abstract
Hydrogen peroxide functions as a bioremediation technology by enhancing natural biodegradation processes in contaminated subsurface environments. This in situ process works by introducing hydrogen peroxide as a chemical source of oxygen, which is necessary for the growth of aerobic bacteria in general and hydrocarbon-degrading bacteria in particular.

Hydrogen peroxide is considered a chemical oxygen source because it generates oxygen as it decomposes, supplying the necessary aerobic environment for biodegradation. Hydrogen peroxide has been used in commercial applications to destroy hydrocarbons such as benzene, toluene, ethylbenzene, and xylene (BTEX) from groundwater, soils, and aquifer sediments. Hydrogen peroxide was initially thought to have promise as a bioremediation tool because it is completely soluble in water and is often the best oxygen source for saturated soils and aquifers below the water table.

In situ biodegradation is limited by the rate at which oxygen is transferred to the contaminant-degrading microorganisms. Uncontrolled decomposition of hydrogen peroxide can result in water becoming supersaturated with oxygen, which can cause gas blockage and reduce permeability around injection points. Conversely, slow decomposition can reduce the oxygen availability in the area being treated. Another limitation of using hydrogen peroxide is its high cost. Costs for hydrogen peroxide range from approximately \$2.81 to \$4.63/kg of oxygen supplied. Due

to its high cost, uncontrolled decomposition or the loss of oxygen equivalents is a serious concern. In addition, hydrogen peroxide is potentially toxic to microorganisms, so the choice of an appropriate concentration level is an ongoing concern.

Technology Cost

In 1993, the cost of using hydrogen peroxide to enhance biodegradation was been reported to be as high as $2.81 to $4.63/kg of oxygen supplied (D13000N, p. 524; D13003Q, pp. 154–158).

In 1987, a full-scale research project was conducted at the Eglin Air Force Base in Florida. The cost of hydrogen peroxide to enhance biodegradation amounted to $3.00 to $4.20/gal ($.79 to $1.11/liter) of water treated for 35% hydrogen peroxide. The cost of the available oxygen was $1.50 to $2.40/lb ($3.31 to $5.30/kg) (D13001O, pp. 1329, 1346).

In November 1988, authors of the Eglin study estimated that four additional years would be required to deliver the necessary oxygen rates for effective remediation. Assuming a continued volatilization rate of 2000 lb/year (907 kg) and that hydrogen peroxide was delivered via a spray system over a 2-acre area (0.8 hectares), total costs for applying hydrogen peroxide would amount to about $1.4 million in nonresearch costs. Authors stated that $1.4 million would be the minimum required for full site cleanup, assuming 100% oxygen utilization. Actual costs could be higher if a lower percentage oxygen is used (D13001O, pp. 1345–1346). (Cost estimates may not include the associated costs for applying hydrogen peroxide, such as labor, equipment, and materials.)

Information Sources

D13001O, Douglas Downey et al., 1988

D13000N, Barbara Prosen et al., 1994

D13003Q, Brown and Norris, 1994

T0389

HydroScience, Inc.

Hydrolytic Terrestrial Dissipation

Abstract

According to the vendor, the hydrolytic terrestrial dissipation (HTD) process is an ex situ process for the treatment of soils contaminated with toxaphene (a chlorinated pesticide) and other pesticides in soils. The process utilizes metal-catalyzed alkaline hydrolysis reactions, ultraviolet (UV) light, and reducing or oxidizing agents to remove chlorine from the contaminant.

The HTD technology was accepted into the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration program in the spring of 1991. However, a suitable site has not yet been provided for field testing of the HTD process.

This technology is neither patented nor proprietary, but it has not been performed by another vendor. All information is from the vendor and has not been independently verified.

Technology Cost

There is no information available about the costs associated with this technology.

T0390

IBC Advanced Technologies, Inc.

SuperLig Ion Exchange Resins

Abstract

IBC Advanced Technologies, Inc. (IBC), has developed an ion exchange material called SuperLig®. The material is designed to remove trace amounts of radionuclides and heavy

metals from large volumes of solution. SuperLig is intended to be used as part of an ex situ treatment train in a packed bed or with the 3 M™Empore™ technology (RIMS2000 Technology Summary Number T0001).

While SuperLig technology is still being developed for use in radionuclide applications, it is commercially available for applications involving the removal of rhodium from automobile catalytic converters, the recovery of bismuth and antimony from copper-refinery streams, and for the extraction of other metals from water.

The ability of SuperLig to adsorb cesium was reduced by a factor of 2 following exposure of the resin to 2.0×10^9rad. The resin performance was inhibited by the direct energy absorbed by the resin during irradiation. Bench-scale degradation studies have shown that the SuperLig resins oxidize in the presence of oxygen. As the resin oxidizes, its cesium removal performance decreases. Also, the chemical stability of SuperLig under caustic conditions is significantly lower than in ambient air or under neutral or acidic conditions. The resin swells in caustic solutions. This swelling may increase the resin's degradation rate. SuperLig resins perform more efficiently at lower flow rates due to the kinetics of the resins' adsorption reactions.

Technology Cost

No available information.

T0391

ICI Explosives Environmental Company

ICI Explosives Incineration Process

Abstract

ICI Explosives Environmental Company (ICIEEC) has developed a rotary kiln incinerator for the treatment of explosives and other hazardous wastes. The purpose of the technology is to offer an alternative to open detonation for remediating materials contaminated with explosives and reactive materials. The ICIEEC facility in Joplin, Missouri, is the only commercial incinerator in the United States that regularly accepts U.S. Department of Transportation (DOT) Hazard Class 1.1 materials. The technology is commercially available.

ICIEEC claims the following advantages of its rotary kiln incinerator system:

- Offers greater control over emissions then open burning/open detonation.
- Minimizes potential future liability.
- Offers competitive prices.

Technology Cost

No available information.

T0392

Idaho National Engineering Laboratory

Biological Destruction of Tank Wastes (BDTW)

Abstract

Biological destruction of tank waste (BDTW) is a separation and volume-reduction technology designed to treat supernatant and sluiced salt cake waste from underground storage tanks. These

wastes are usually composed of various radionuclides and toxic metals concentrated in a nitrate salt solution. According to the vendor, the BDTW system would ideally be located adjacent to storage tanks.

The technology's bacteria act as metal and radionuclide adsorbers and also as denitrification catalysts that reproduce themselves at ambient temperature and pressure.

This biological process is designed to treat the highly saline underground and storage tanks of the Hanford Site, which contain various radionuclides, transuranic, and toxic metals, and organic materials. The organic materials are principally salt cake, consisting mainly of nitrate salts and lower levels of metals, and concentrated supernatant whose composition is in equilibrium with the waste sludge and salt cake. It could be applicable to treat similar waste of other tank farms.

This process may also be suitable for waste streams from metals reprocessing facilities in addition to those waste streams from nuclear fuels processing and reprocessing facilities.

Technology Cost
No available information.

T0393

Idaho National Engineering and Environmental Laboratory

In Situ Grouting and Retrieval

Abstract
Idaho National Engineering and Environmental Laboratory (INEEL) has developed an innovative in situ grouting and retrieval (IGR) technology for hot-spot or full-pit removal of buried transuranic wastes in shallow land burial sites. IGR is a contamination control technology that can be applied to waste-removal sites and has been shown to be effective in fine, silty-clay soils. The technology involves jet grouting to solidify the buried wastes, then applying an expansive grout (demolition grout), followed by remote excavation using a bridge crane mounted system. Innovative grouting technology can be used to create a U-shaped stabilization wall to support hot-spot retrieval or to create a stabilized monolith of buried waste for in situ disposal. The technology is commercially available.

INEEL claims the following advantages using in situ grouting:

- Faster than baseline technology (archaeological removal) by at least a factor of 5.
- Lower requirements for contamination control systems should lead to less time wasted decontaminating equipment.
- Cheaper than baseline technology (archaeological removal).
- Safer than baseline technology because stabilization prior to retrieval agglomerates the contaminants and strengthens the excavated wastes, minimizing waste handling concerns.

If the drilling equipment strikes a pressurized gas cannister, explosions are possible. This possibility demands the use of remote operation of the drilling procedure. The effectiveness of the demolition grout was found to be highly dependent on the temperature. Metal debris can disrupt retrieval procedures.

Technology Cost
The U.S. Department of Energy (DOE) has estimated the cost of in situ grouting technology. For full pit removal, the estimated cost was \$19.1 million for the first acre and \$15 million for each additional acre. The cost includes grouting and waste management, excavation, project

management, secondary waste management, and equipment. The cost savings over baseline technology (retrieval, packaging, and storage) is approximately $241 million. The estimated cost for in situ waste stabilization/disposal using jet grouting with TECT as the grout is approximately $15.1 million for a 1-acre site. This estimate includes the stabilization and containment costs and the secondary waste is assumed to be classified as low-level radioactive waste. See Table 1 for detailed cost information. For the interim storage/retrieval application using jet grouting with WAXFIT, the estimated cost for a 1-acre site is $19.9 million. Table 2 contains detailed information on the cost estimates (D18812Z, pp. 12–13).

Based on 1995 estimates, the cost for the removal of a hot spot with dimensions 40 ft by 60 ft by 10 ft deep with the grouting extending 10 ft beyond the hot spot was estimated at $3.295 million. These costs could double or triple based on the project management, the need for containment devices other than weather shields, health physics support, and sampling required during cleanup operations. No cost estimate is provided for treatment and final disposal (D13730E, pp. vi, 120). Details of the cost estimates are given in Table 3.

TABLE 1 Cost of In Situ Stabilization/Disposal Using Jet Grouting

Category	Explanation	Cost
	1-Acre Site Using Jet Grouting with TECT	
Grouting	14,000 holes at $250/hole	$3.5 million
Secondary waste management	Crew of 2–3 persons at $125,000/year	$375,000
Grout material	$5/gal at 57% voids; 1.85×10^6 gal of grout	$9.2 million
Management	10% of total cost	$1.3 million
Profit	6% of total cost	$0.78 million
Total	1-acre site	$15.1 million
Savings over baseline		$185 million

Source: Adapted from D18812Z, p. 12.

TABLE 2 Interim Storage/Retrieval Option Using Jet Grouting with WAXFIT

Category	Explanation	Cost
	Full Pit Retrieval for a 1-Acre Pit, 10 ft deep	
Grouting	14,000 holes at $250/hole	$3.5 million
Secondary waste management	Crew of 2–3 persons at $125,000/year	$375,000
Retrieval capital	$2 million remote retrieval system; $2 million weather shield	$4 million
Retrieval operations	3-person crew at $500/day/person at 200 yd^3/day	$127,000
Grout material	$5/gal at 57% voids; 1.85×10^6 gal of grout	$9.2 million
Management	10% of total cost	$1.7 million
Profit	6% of total cost	$1.03 million
Total	1-acre site	$19.9 million
Savings over baseline		$180 million

Source: Adapted from D18812Z, p. 13.

TABLE 3 First-Order Engineering Estimates of In Situ Grouting and Retrieval Costs

Category	Explanation	Cost
	Full Pit Removal of a 1-Acre Site	
Grouting	24,000 holes at $250/hole	$6,000,000
Materials	24,000 yd^3 at $100/$yd^3$	$2,400,000
Fracturing	24,000 holes at $1100/hole	$2,400,000
Retrieval (labor)	3-person crew at 200 yd^3/day 255 labor days at $500/day	$127,000
Retrieval (remote unit)	Remote excavator	$1,500,000
Total		$12,400,000
	Retrieval of a 40-ft by 60-ft by 10-ft Deep Hot Spot	
Grouting	1968 holes at $250/hole	$492,000
Materials	Portland cement	$648,000
Fracturing		$648,000
Retrieval (labor)	Same labor rates as full pit	$7,000
Retrieval (remote unit)	Remote excavator	$1,500,000
Total		$3,295,000

Source: Adapted from D13730E, p. 120.

Innovative grouting is approximately 90% cheaper than baseline technology of retrieval, packaging, and storage (D18812Z, p. 1).

Information Sources

D13730E, Idaho National Engineering Laboratory, 1995

D152023, WEBTECH, 1994, web page

D18812Z, U.S. DOE, 1998

T0394

Idaho National Engineering Laboratory/Brookhaven National Laboratory

Modified Sulfur Cement Encapsulation

Abstract

Idaho National Engineering Laboratory (INEL) and Brookhaven National Laboratory (BNL) are researching applications of modified sulfur cement encapsulation as a final waste form for hazardous and mixed waste. Modified sulfur cement is a polymer composite material consisting of 95% by weight sulfur, 2.5% by weight dicyclopentadiene, and 2.5% by weight oligomers of cyclopentadiene. It melts at approximately 239°F and pours optimally at 275°F. The material solidifies into a strong, leach-resistant final waste form. BNL has evaluated the technology in bench-scale tests, and is offering nonexclusive licenses of the technology. INEL has evaluated a full-scale system using commercial mixing machinery.

BNL claims the following advantages of sulfur polymer cement:

- No chemical reaction occurs to solidify final waste form.
- Compatible with many waste types.

- Not subject to the failure mechanisms associated with other solidification technologies, such as conventional cement stabilization.
- Can support higher waste loadings and when solidified has greater compressive and tensile strength than conventional cement stabilization.
- Final waste form satisfies Nuclear Regulatory Commission and U.S. Environmental Protection Agency (EPA) regulatory criteria for disposal.

Combining sodium nitrate salts with modified sulfur cement is not recommended, as the mixture could react. Modified sulfur cement is not compatible with highly soluble compounds, expanding clays or organic materials. Chemical corrosion of the final waste form can occur in strong (>10%) alkaline solutions, oxidizing solutions such as chromic acid or hypochlorite, and in the presence of metal slimes like copper. Modified sulfur cement cannot accept water, so wastes must be dried prior to treatment. The technology is not suitable for the stabilization of wastes with self-generating temperatures greater than 212°F. If temperatures reach 310°F, a phase change occurs in modified sulfur cement, and hydrogen sulfide gas is released.

Technology Cost
No available information.

T0395

Idaho Research Foundation, Inc., and White Shield, Inc.

Simplot Anaerobic Biological Remediation (SABRE)

Abstract
The Simplot Anaerobic Biological Remediation™ (SABRE™) process is a patented, ex situ technology used to treat soils contaminated with nitroaromatic compounds. Researchers isolated a selection of anaerobic bacteria based on their ability to degrade nitroaromatic compounds with the total destruction of intermediate compounds by the completion of treatment. These bacteria are the basis of the SABRE process.

Idaho Research Foundation, Inc., is offering field-of-use and site-specific licenses for the technology. White Shield, Inc., has acquired a worldwide, field-of-use license to use the technology at agricultural sites contaminated with herbicides and a site-specific license for treating range residue at a firing range in Washington.

According to the vendor, the following benefits have been associated with use of the SABRE process:

- Complete anaerobic biodegradation of nitroaromatic compounds is possible without the accumulation of toxic intermediates.
- Degradation of nitroaromatic compounds is possible at temperatures much lower than optimal for most bioremedial technologies.
- Following treatment, high organic carbon and mineral content in soils make them ideal for reuse on-site.
- Treatment can be completed in less than one season.

Each site must be assessed by treatability studies to evaluate the practicality of using the SABRE system. The site must be large enough to provide space for the modular bioreactor or for the lined pits. An important limiting factor is the toxic effect of co-contaminants (e.g., petroleum hydrocarbons) on the microorganisms. Another limitation of this technology is temperature. As the temperature falls, biological activity slows and degradation rates of contaminants follow.

Technology Cost

The U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration program tested the SABRE process at two sites, one in Ellensburg, Washington, and one in Weldon Springs, Missouri. An economic analysis of the costs, based on remediation of 3824 m^3 of contaminated soil, was included in EPA's reports. Generally, the larger the volume of soil to be treated, the lower the price per cubic meter. Costs were divided into three parts: costs assessed to client by the vendor, special costs imposed by the J.R. Simplot Company (former vendor of the SABRE technology), and costs that are assumed to be the responsibility of the site owner (D11075Y, p. 31; D113473, p. 30). The results are shown below.

Costs typically assessed to the client by the vendor at the TNT-contaminated site in Weldon Springs, Missouri, were estimated to be $147/$m^3$ (D11075Y, p. 33). Costs at the dinoseb-contaminated site in Ellensburg, Washington, were estimated to be $127/$m^3$ (D113473, p. 32). Neither estimate includes profit by the vendor. See Table 1 for a breakdown of these costs.

Special costs of up to $131/$m^3$ have been imposed by the J.R. Simplot Company. This additional expense depends on site characteristics and may include supplementary technical assistance, soil enhancements, nutrients, or a carbon source in the form of Simplot potato processing by-product (D11075Y, p. 32).

Costs that are assumed to be the obligation of the responsible party or site owner are not included in the estimate. These costs are site-specific and include:

- Preliminary site preparation
- Excavation of the contaminated soil
- Permits and regulatory requirements
- Initiation of monitoring and sampling programs
- Effluent treatment and disposal
- Environmental monitoring
- Site cleanup and restoration (D113473, p. 31)

TABLE 1 Cost Breakdowns for the SITE Demonstrations of the SABRE Technology

Cost	Weldon Springs, MO (TNT)	Ellensburg, WA (Dinoseb)
Technology specific site and facility preparation	$32.37 (22%)	$32.37 (25.4%)
Equipment	$33.15 (22.6%)	$27.18 (21.3%)
Startup and fixed	$6.65 (4.5%)	$18.41 (14.5%)
Labor	$28.82 (19.6%)	$12.97 (10.2%)
Supplies	$0.24 (0.2%)	$0.16 (0.1%)
Consumables	$34.86 (23.7%)	$34.28 (26.9%)
Residuals and waste shipping, handling, and transportation cost	$0.18 (0.1%)	$0.12 (0.1%)
Analytical	$10.05 (6.8%)	$1.67 (1.3%)
Facility modification, repair, and replacement	$0.77 (0.5%)	$0.22 (0.2%)
Total	$147.00/$m^3$	$127.00/$m^3$

Source: Adapted from D11075Y and D113473.

The J.R. Simplot Company reported that total costs for a typical site range from \$200 to \$1000/yd^3. The total costs varied based on the quantity of waste to be treated, depth to contamination, initial and target contaminant concentrations, required pretreatment, site preparation, and characteristics of the soil (D22175A, p. 6).

According to J.R. Simplot Company, the costs for treating 20 yd^3 of TNT-contaminated soil at the U.S. Department of Defense's (DOD's) Bangor Submarine Base in Bangor, Washington, were estimated at \$700/yd^3 (D22175A, p. 9).

During a field test of SABRE technology conducted at the DOD's Iowa Army Ammunition Plant, the U.S. Army Environmental Center evaluated the performance and cost of biotreatment as an alternative to incineration of munitions. Cost projections for this demonstration estimate a unit cost of approximately \$300 to \$350/yd^3 (D18531T, p. 262).

Information Sources

D11075Y, U.S. EPA, 1995

D113473, U.S. EPA, 1995

D18531T, Hampton, undated

D22175A, U.S. EPA Reachit, undated

T0396

IEG Technologies Corporation

Coaxial Groundwater Ventilation (KGB)

Abstract

Coaxial groundwater ventilation (German abbreviation: KGB) technology is used in the remediation of groundwater and of perched water contaminated with volatile hydrocarbons. It can also be employed to inject oxygen into the groundwater for the enhancement of microbial degradation.

KGB is a method patented by IEG Industrie-Engineering-GmbH, Reutlingen, Germany (D16432J, p. 2). KGB is the forerunner to IEG's UVB technology, which is also included in the RIMS library/database (T0398). UVB is now emphasized by the vendor and used more frequently than KGB, although KGB remains a commercially available technology.

The KGB technology consists of a combination of soil air venting with in situ groundwater stripping ("push-and-pull technique"). Clean compressed air is forced into a pressurized air distributor located between the capillary fringe and the aquifer base. The distributor's location depends on the vertical pollutant distribution.

A continuous circulation of groundwater is generated in the area surrounding the remediation well, as aquifer waters replace the annulus water. The circulation thus delivers new contaminants to the stripping zone. Volatile contaminants dissolved in the groundwater are transferred from the liquid to the gas phase and are extracted from the groundwater surface via a double-cased screen. Soil air from the unsaturated zone is also extracted and transported to the off-gas treatment system.

According to the vendor, a special advantage of the KGB technology is its ability to effectively remediate the capillary fringe. Also, the difficulties that arise during conventional remediation procedures due to contaminated perched water, which collects in the remediation well, do not occur with the KGB. Perched water can be stripped directly in the ground without having to pump it to an above-ground treatment system.

Technology Cost

No available information.

T0397

IEG Technology Corporation

BLK

Abstract

The BLK (German: Boden-Luft-Kreislauffuhrung) technology is a directed soil air circular flow system for soil air venting. It was designed to remove volatile contaminants, such as chlorinated or aromatic hydrocarbons and/or biodegradable substances, from the vadose zone or capillary fringe. It can also be used for injection of gases into the soil for stimulation of biological or chemical degradation of biodegradable contaminants. It is a patented, commercially available technology.

The BLK is designed with an upper and a lower screened section in a bore hole, each of which is separately connected to the same above-ground blower. The two screened sections are separated by a bentonite seal. This arrangement allows air to be withdrawn from either segment individually or from both simultaneously. The air extracted from one screen, after passing through a suitable remediation unit (activated carbon filter or catalytic oxidation unit), is then reinjected into the subsurface through the other screen, resulting in a vertical circular air flow around the well.

The BLK, in contrast to many traditional venting methods, is capable of generating a directed circulation through the source of the contamination, especially in low-permeability soils. The circulation direction is reversible and can be adjusted according to the position of the contaminant in the soil.

Technology Cost

No available information.

T0398

IEG Technologies Corporation

Vacuum Vaporizer Well (UVB)

Abstract

The vacuum vaporizer well [in German: Unterdruck-Verdampfer-Brunnen (UVB)] is an in situ technology used to treat groundwater contaminated with chemicals that are amenable to air stripping. UVB combines air-lift pumping with air stripping (which occurs within the well) to remove volatile organic compounds (VOCs). The well has two screened portions, one at the top of the well straddling the water table and one at the bottom of the well. The well is normally operated with a vacuum pulling water from the bottom section, but the process can be reversed so that water is pulled from the upper screened section of the well. UVB circulation increases oxygen concentration in the circulation area of the well, which can promote microbial growth and increase biodegradation rates.

UVB is a full-scale, commercially available technology that provides an alternative to pump-and-treat methods. The vendor states that the technology has been applied at over 143 sites in Europe and 42 sites in the United States.

The UVB system has several potential advantages:

- Treats groundwater in the subsurface, eliminating extraction and disposal costs.
- Requires little space for operation.
- Is equipped with a floating aerator that adjusts to fluctuations in the water table.

- Provides long-term protection by eliminating organic contaminants from soil and groundwater.
- Minimizes off-site contaminant migration.
- Installs below ground.
- Has minimal operating requirements.

The UVB technology has limitations in thin aquifers and in areas with very shallow groundwater (less than 5 ft). The thickness of the saturated zone affects the radius of the circulation cell. Precipitation, soil type, and other site-specific conditions can also impact the effectiveness of the UVB system.

Technology Cost

According to the EPA, the actual cost of UVB applications are site specific and depend on the volume of contaminated soil, soil characteristics, depth to groundwater, types and concentrations of contaminants, and the remediation goals. Capital costs for the installation of a single UVB unit are estimated at $180,000. The estimated operation and maintenance (O & M) costs are $72,000 for the first year and $42,000 for subsequent years. Total costs for operating a single UVB system are estimated at $260,000 for 1 year, $340,000 for 3 years, $440,000 for 5 years, and $710,000 for 10 years. The estimated costs of treatment per 1000 gal of groundwater are $260 for 1 year, $110 for 3 years, $88 for 5 years, and $71 for 10 years (D11496F, p. 7; D22532B, p. ES-5, 3–1).

Another cost estimate placed the total remediation costs at $253,000. This included $64,000 for planning, organization, project management, and remediation equipment; $44,000 for field work; $74,000 for laboratory analytical work; $29,000 for drilling costs; and $42,000 for activated carbon and regeneration (D22531A, p. 22).

Table 1 shows a cost comparison of UVB, pump-and-treat technology alone, and pump-and-treat technology combined with excavation and bioremediation at a site where the groundwater was contaminated with benzene, toluene, ethylbenzene, and xylene (BTEX) (D122827, p. 1.4).

In 1995, a field demonstration of UVB was conducted at the U.S. Department of Defense's (DOD's) Port Hueneme Naval Exchange site in California. The site is a former gasoline station contaminated with approximately 11,000 gal of gasoline. The cost of this UVB application was approximately $184,000. This cost estimate included capital and O & M costs but did not include the costs associated with research and development (D188709, p. 12).

Between 1993 and 1994, UVB technology was demonstrated at a solvent disposal site on the DOD's March Air Force Base in California. The capital cost for one UVB well was approximately $180,000. First and second year O & M costs were approximately $75,000 and $42,000, respectively. The treatment costs for the trichloroethene-(TCE)-contamination was approximately $260 per 1000 gal of treated groundwater. The UVB well was designed to treat 1,000,000 gal per year (D188709, p. 9).

TABLE 1 Estimated Remediation Costs for BTEX[a]-Contaminated Ground Water

	Excavation/Bioremediation and Pump and Treat	Pump-and-Treat Alone	UVB
Investigation	$26,000	$26,000	$26,000
Design and oversight	$73,000	$45,000	$52,200
Construction	$792,500	$157,800	$210,200
Operation and maintenance	$100,000	$971,200	$223,900
Total	$991,500	$1,200,000	$512,300

Source: D122827.

[a] Benzene, toluene, ethylbenzene, and xylenes.

At the Cabot/Kopper's Superfund Site, in Gainesville, Florida, remediation using the UVB technology cost approximately $225,000. This figure included $8000 for mobilization; $85,000 for monitoring, sampling, testing, and analysis; $3000 for site work; $129,000 for equipment related costs; $4000 for demobilization; and $26,000 for administration. The vendor estimated that this system would cost approximately $50,000 less the following year (D190970, p. 21; D22541C, p. 2).

Costs for a 5-month demonstration at the Sweden-3 Chapman Superfund Site in Sweden, New York, were approximately $153,000. This figure included $15,000 for mobilization, $15,000 for decontamination and demobilization, $31,000 for the final report, $61,000 for operational costs during the first half of treatment, and $31,000 for operational costs during the second half. It cost an additional $82,000 to extend the project for another 7 months (D190970, p. 22). At the end of the 14-month demonstration, 628 yd^3 of soil had been treated at an estimated cost of $347/$yd^3$. Based on these results, the EPA estimated that it would cost $149/$yd^3$ to treat the remaining 13,000 yd^3 of contaminated soil at the site. This estimate included the use of 22 UVB wells operating over a 14-month period. If treatment time were increased to 3 years, the costs would increase to approximately $259/$yd^3$. If the treatment time were increased to 5 years, treatment costs would average $375/$yd^3$ (D22041X, p. 8).

At the Massachusetts Military Reservation in Cape Cod, Massachusetts, 2 UVB wells and 2 NoVOCs™ (RIMS Technology Summary T0599) wells were installed to remediate TCE. The cost of the entire demonstration was approximately $3,600,000. Drilling and construction at the site accounted for the majority ($2,100,000) of the expenses. Other funds were used to pay for sampling and analysis, project management, design and preconstruction planning, and system evaluation reports (D19096Z, p. 11).

In the Rhine-Ruhr area of Germany, UVB technology was used to treat 1550 kg of volatile non-aqueous-phase liquids (NAPLs). The total cost of the system was $352,000. This project spent 21.8% of this money on site investigation and planning, 21.5% on monitoring and field work, 8.2% on analytical work, 15.3% on borings and UVB installation, 24.1% on granular activated carbon treatment and NAPL disposal, and 9.1% on energy. The monthly operating costs for this project averaged $4000 (D126318, p. 113).

Information Sources

D11496F, EPA SITE Technology Capsule, 1995
D122827, The Hazardous Waste Consultant, 1995
D126318, U.S. EPA, 1994
D188709, U.S. EPA, 1998
D19096Z, U.S. EPA, 1998
D190970, U.S. EPA, 1998
D22041X, U.S. EPA, 1999
D22531A, Miller, Roote, 1997
D22532B, U.S. EPA, 1999
D22541C, U.S. EPA, undated

T0399

IEG Technologies

Groundwater Circulation Wells (German abbreviation: GZB)

Abstract
Groundwater circulation wells (German abbreviation: GZB) are constructed with two screened sections; one placed at the bottom of the aquifer, and one approximately at the water table. In a GZB circulation cell, water is withdrawn through one screened section and reinjected through

the other, creating a three-dimensional vertical flow. The well can also be used to inject materials (nutrients, oxygen, etc.), encourage in situ biodegradation of organic contaminants, or transport groundwater to the surface for ex situ treatment.

GZB is patented by B. Bernhardt of the German company IEG mbH, Reutlingen, Germany. The technology is available commercially from IEG's U.S. subsidiary, IEG Technologies, Charlotte, North Carolina.

According to the developer, GZB technology has several advantages:

- Requires a small amount of space for operation.
- Uses little energy.
- Minimizes site disturbance.
- Treats groundwater in situ.

Site hydrogeology can affect the sphere of influence of a GZB. A GZB well should be used to remediate only one aquifer, either confined or unconfined, and should not connect different aquifers.

Technology Cost
No available information.

T0400

IIT Research Institute

Radio Frequency Heating

Abstract
The radio frequency (RF) heating process heats soils contaminated with volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and pesticides in situ by means of an electrode array applied in bore holes drilled through the soil, thereby potentially enhancing soil vapor extraction (SVE) technologies. The electrodes are designed to allow RF power to be applied while collecting vapors by applying a vacuum down hole.

Two heating processes are based on this technology. The first, in situ RF heating, uses electromagnetic energy in the 2- to 13-megahertz (MHz) frequency range to heat soil to a temperature ranging from 100 to 300°C. The second process uses 60-Hz alternating current power to heat soil to the boiling point of water. This low-frequency process is called the in situ electromagnetic (EM) heating process. The RF process is intended to remove high-boiling-point chemicals in the vadose zone, and the EM process is suitable for use when the soil contains VOCs in the vadose zone.

Advantages of this process include the following:

- In situ treatment minimizes earth removal, thereby minimizing odors, fugitive emission, and dust hazards.
- Only 0.5 to 1% of the soil treated needs to be removed to create the electrode bore holes.
- The gas stream produced is treated on-site.
- Process equipment is trailer-mounted and mobile.

Limitations of this technology include the following:

- High moisture or presence of groundwater in the treated area requires excessive power requirements to heat the soil.
- The method cannot be used in treatment zones with large buried metal objects.

This technology is currently commercially available.

Technology Cost

Based on data from the Volk Air National Guard Base demonstration, it is estimated that the treatment cost varies between $28 and $60 per ton ($31 and $66 per metric ton) of soil treated. Based on bench-scale testing, treating a 3-acre (1.2-hectare) site to a depth of 8 ft (2.4 m) containing 12% moisture raised to a temperature of 170°C costs $42 per ton ($46 per metric ton). Treating a site with these parameters would take approximately 1 year. The initial capital equipment investment for full-scale projects is approximately $1.5 million (D12688P, p. 47).

Based on data from the Sandia National Laboratory demonstration, the cost of operating this technology was estimated for treating 4600 m^3 of soil at a single site. The total cost of treatment is estimated to be $160 m^3 of soil remediated. This cost is based on treating the soil in three equal batches of approximately 1500 m^3. Each batch can be treated in a period of 2 months using a 200-kw-amp RF power source. This cost includes the following parameters:

- Labor
- Consumables
- Startup
- Capital equipment
- Permitting
- Site preparation
- Demobilization
- Analytical
- Effluent treatment
- Utilities (D12805C, p. 5)

Information Sources

D12688P, U.S. EPA, 1991
D12805C, Dev and Phelan, 1996

T0401

Imbibitive Technologies Corporation (IMTECH)

Imbiber Beads

Abstract

Imbiber Beads® are spherical plastic particles that can absorb certain liquid organic contaminants. Absorption is a process where the material taken up is distributed throughout the solid body of the absorbing material. This is different than adsorption, another common remediation technology in which the target substance attaches only to the surface of the adsorbent material.

A common use of Imbiber Beads is to stop spills from escaping into the environment. The Beads® do not change the nature of the contaminant; they simply absorb it, creating a more easily recoverable and transportable waste product.

According to the vendor Imbiber Beads should not be used with oxidizers.

Technology Cost

Table 1 is a price list for the IMTECH Imbiber products as of January 1997 (in U.S. dollars). Once contact has been made with a compatible organic liquid, the Beads will absorb up to 27

TABLE 1 IMTECH Price List (January 1997)

Product Description		1–49	50–300	300+
Imbiber beads	40-lb drum (18.1 kg)	\$440.00/drum \$11.00/lb	\$380.00/drum \$9.50/lb	\$340.00/drum \$8.50/lb
Bead/sand blend	25-lb cubitainer (11.3 kg)	\$113.75/cubitainer \$4.55/lb	\$98.75/cubitainer \$3.95/lb	\$88.75/cubitainer \$3.55/lb
Packets	36/carton (7 inch × 7 inch)	\$99.00/carton \$2.75 each	\$93.60/carton \$2.60 each	\$86.40/carton \$2.40 each
Pillows	6/carton (14 inch × 21 inch)	\$91.80/carton \$15.30 each	\$87.60/carton \$14.60 each	\$81.00/carton \$13.50 each
Blanket	4/carton (21 inch × 42 inch)	\$189.00/carton \$47.25 each	\$180.00/carton \$45.00 each	\$168.00/carton \$42.00 each
Mini-Boom	12/carton (7 inch × 42 inch)	\$189.00/carton \$1.75 each	\$180.00/carton \$15.00 each	\$168.00/carton \$14.00 each
Aquabiber™	40 lb drum (18.1 kg)	\$270.00/drum \$6.75/lb	\$232.00/drum \$5.80/lb	\$210.00/drum \$5.25/lb
Unibiber™	25 lb/cubitainer (11.3 kg)	\$113.75/cubitainer \$4.55/lb	\$98.75/cubitainer \$3.95/lb	\$88.75/cubitainer \$3.55/lb

volumes of the organic liquid and swell up to 3 diameters depending upon the liquid and other variables such as temperature (D17058L).

Information Source

D17058L, IMTECH American Price List, 1997

T0402

Imperial Petroleum Recovery Corporation

MST-4000

Abstract

The MST-4000™ is a new technology that utilizes radio frequency (RF) electromagnetic (microwave) energy to separate the water, oil, and solids in crude oil sludge. It is portable, and recovers virtually all available hydrocarbons. The MST-4000 is applicable for most emulsions, including float waste, slop oil emulsion solids, heat exchanger bundle cleaning sludge, American Petroleum Institute (API) separator sludge, and leaded tank bottoms (D13385H, p. 1).

Anticipated locations for using the technology include refineries, upstream transfer points, ship-side, well-heads, and sludge storage pits and tanks. The vendor claims that up to 95 to 99% of a sludge's volume can be reclaimed and resold (D13383F, p. 1).

The first unit built was located near Houston, Texas, for testing in the summer/fall of 1996. Final field testing is expected to conclude with a demonstration (D13385H, p. 1). Because this is a new technology, very little information has been published as of yet, and most of the information contained herein is vendor supplied.

Technology Cost

Currently, Imperial leases MST-4000 units for \$2.5 million each. On May 8, 1996, Imperial Petroleum announced that it had leased the first unit to Saudi Imperial, who will have exclusive rights to market and operate the technology in Saudi Arabia. Each unit there is expected to cost an additional $2 million in royalty fees each year, based on the volume of oil separated and sold (D13386I, p. 1).

The vendor claims that this technology will cost 47% of what normal centrifuge systems do, 44% of heat/pressure systems, and 7% of incineration (D130381).

Because only 5 to 20% of the original volume of crude oil sludge remains after treatment, transport and disposal fees are also reduced. Resale of the recovered crude is expected to offset part of the cost.

Information Sources

D130381, Environtech, 1996

D13386I, Imperial Petroleum Recovery Corporation, 1996

T0403

IM-TECH

Solidification/Stabilization Process

Abstract

The IM-TECH solidification/stabilization technology is designed to immobilize contaminants in soil or sludge by binding them into a concretelike, leach-resistant mass. IM-TECH indicates that this process is suitable for soil and sludge contaminated with organic compounds, heavy metals, oil, and grease. These wastes can be treated together or individually. According to the vendor, contaminated soil or sludge can be excavated and/or treated in situ. If excavated, the waste is screened for oversized material and fed into a field blending unit.

IM-TECH's solidification/stabilization process was evaluated in the Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration program in 1987. The current status and commercial availability of the technology is unknown.

Technology Cost

Based on tests conducted at a former oil reprocessing plant in Douglassville, Pennsylvania, costs range from $40 to $60 per ton for processing heavy-metal waste and between $75 to $100 per ton for wastes with heavy organic content (D16650R, p. 80).

Information Source

D16650R, U.S. EPA, 1991

T0404

In situ grouting — General

Abstract

In situ grouting involves the injection of cement, clay, or other materials into the subsurface to contain or immobilize solid or liquid waste by lowering the soil's permeability. These technologies can be used to form vertical, angled, or horizontal barriers depending on the configuration of the injection ports. Grouting has been used for decades to stabilize hazardous and low-level radioactive waste. There are a number of different grouting techniques including jet grouting, permeation grouting, soil mixing, multipoint injection technology, Rockwell Hanford Operations (RHO), and clay-grouting technology. The selection of an in situ grouting technology depends

on the characteristics of the soil and grout, consistency required for placement, and required properties of the barrier or solidified product. The grouting material used is site specific and depends on the technology, contaminant compatibility, and the subsurface composition.

The ability of a soil to receive grout depends on the permeability of the soil and the viscosity of the grout. Soils with permeabilities less then 10^{-6} cm/sec are not amenable to grout, and soils with permeabilities greater than 10^{-1} cm/sec require suspension grouts or chemical grouts containing filler materials. Gravels and sands tend to be groutable while soils containing more than 20% silt or clay are difficult or impossible to grout. Typically, higher viscosity grouts are better suited to high permeability soils (soils with larger void spaces), and low-viscosity grouts are necessary when the soil has a low permeability.

Grouting technologies have been commercially available for many years, however, new techniques are also being developed. In addition, there is considerable work being done to test the performance of alternative grouts in different subsurface environments using different installation techniques.

Advantages of in situ grouting technology include the following:

- No excavated soil requiring disposal.
- Can be installed in confined places without disrupting the structure.
- Can form barriers of different configurations.
- Different grouts can be used depending on the contaminant.

Limitations of in situ grouting technology include the following:

- Restricted to soils with moderate to high permeabilities.
- Difficult to direct the flow of grout, especially in heterogeneous soils.
- Hard to predict grout penetration radius.
- Grout must be compatible with placement technology.
- Susceptible to cracking due to wet/dry cycling.

Technology Cost

Factors that may influence the cost of in situ grouting include the grouting technology selected, backfill material, subsurface conditions, length and depth of contaminated area, cost of labor and materials, access to area, season and weather, contractor experience, and required level of personal protection. In addition to the above factors, the cost of jet grouting may depend on the width of the wall and ranges from \$15 to \$80 per vertical square foot (D18730Y, p. 59; D18982G, p. 23). For columnar walls installed using jet grouting, the cost is typically \$15 to \$20/ft^2. This estimate does not include the cost of grouting materials, waste disposal, and contingencies. The cost of in situ grouting using permeation grouting methods is highly dependent on the cost of directional drilling. Cost estimates for directional drilling are \$7 to \$17/ft^2 not including grouting materials, waste disposal, surface support equipment, and contingencies (D187397, p. 205).

Tables 1 and 2 provide estimated cost information for walls emplaced using different grout materials and methods of installation. Table 3 is a comparison of the estimated costs of alternative installation techniques for vertical barriers in Europe.

The process costs for Geo-Con's deep soil mixing were \$194/ton (\$214/metric ton) of contaminated soil for the one-auger system used in the 1988 Florida Superfund Innovative Technology Evaluation (SITE) demonstration, and \$111/ton (\$122/metric ton) for the commercial four-auger operation that later finished the job there (D17048J, pp. 25–29). More recently, larger equipment has reduced process costs to as low as \$15/ton (\$16.50/metric ton) plus the cost of chemical additives (D10710Y, p. 78). Geo-Con, Inc., reports more typical process costs of \$40 to \$50/yd^3 (\$52 to \$65/m^3) plus chemical costs (D12569J, p. 1).

TABLE 1 Estimated Costs and Production Rates for Installation of Grout Walls

Wall Type	Width (ft)	Depth (ft)	Unit Cost ($/ft^2)	Production Rate (ft^2/10 hr)
Soil bentonite	2–3	80	2–8	2500–15000
Cement bentonite	2–3	80	5–18	1000–8000
Biopolymer drain	2–3	70	7–25	1500–5000
Deep mixing	2.5	90	6–15	1000–8000
DM structural	2.5	90	15–30	1000–3000
Jet grouting	1.5–3	200	30–80	300–2500
Grout curtain	One row	200	40–100	200–1000

Source: Adapted from D18730Y, p. 60.

TABLE 2 Estimated Costs for Alternative Grout Materials and Installation Methods

Material Type	Installation Method	Price ($/ft^2)
Soil–bentonite	Slurry trench	3–8
Cement–bentonite	Slurry trench	6–14
Soil–bentonite	In Situ mixing	5–9
Soil–cement	In Situ mixing	6–14

Source: Adapted from D18730Y, p. 60.

TABLE 3 Vertical Containment Barrier Costs in Europe

Type	Cost ($/ft^2)	Production Rate per 10 hr (ft^2)
Slurry/backhoe	6–10	3000–5000
Slurry + membrane/backhoe	10–16	2000–3000
Slurry/clamshell	16–20	1000–1500
Slurry + membrane/clamshell	18–22	800–1200
Plastic concrete/clamshell	25–30	1000–1500
Plastic concrete/cutter	50–80	
Vibratory beam	3–5	3500–5000
Jet grouting	15–30	2500–3500
Colmix (DM)	12–16	250–500

Source: Adapted from D18730Y, p. 60.

Information Sources

D18730Y, Filz et al., 1995

D18982G, Pearlman, 1999

D187397, Landis et al., 1995

D17048J, U.S. EPA, 1990

D10710Y, U.S. EPA, 1995

D12569J, COPA, undated web site

D14354E, Allan et al., 1992

T0405

In Situ Oil Skimmers — General

Abstract

In situ oil skimmers are commercially available for the recovery of free product [i.e., light non-aqueous-phase liquids (LNAPLs) such as oil, grease, or other hydrocarbons] floating on the water table. Oil skimmers can be used alone or in conjunction with other remediation technologies, such as (in situ) soil vapor extraction, bioventing, or bioremediation, or (ex situ) membrane filters, coalescers, or chemical processes. The technology is implemented in situ by lowering the skimmers into wells located in the zone of contamination.

Oil skimmer technology is used primarily in cases where a fuel hydrocarbon lens more than 20 cm (8 inches) thick is floating on the water table. The free product is generally drawn up to the surface by a pumping system. Following recovery, it can be disposed of, reused directly in an operation not requiring high-purity materials or purified prior to reuse. Systems may be designed to recover only product, mixed water and product, or separate streams of product and water (i.e., dual-pump or dual-well systems).

Technology Cost

Some representative costs for in situ oil skimmers published by the U.S. Department of Energy (DOE) in 1996 were $4500 per month for a hand bailing system, $1200 to $2000 per month for a skimming system, and $2500 to $4000 per month for a dual pumping system. Key cost factors for free-product recovery include waste disposal, potential for sale of recovered product for recycling, on-site equipment rental, installation of permanent equipment, and engineering and testing costs (D167855).

Information Source

D167855, DOE, February 1996

T0406

In Situ Soil Vapor Extraction (SVE) — General

Abstract

Soil vapor extraction (SVE) (also called vacuum extraction, soil venting, or in situ vaporization) is used to remove volatile organic compounds (VOCs) and some semivolatile organic compounds (SVOCs) from contaminated soil. SVE systems apply a vacuum in an extraction well to remove soil vapors. This creates a negative pressure that causes the volatilization of some chemicals in the vadose zone of the soil. The technology has also been used to extract non-aqueous-phase liquid (NAPL). Contaminant volatilization is often enhanced through the use of air injection wells to supply unsaturated air into the vadose zone of the soil.

Soil vapor extraction was first used in the 1970s as a technique to remove vapor from landfills. During the 1980s, SVE was used extensively to remediate contaminated soil from leaking underground storage tanks. The technology has been applied to many hazardous waste sites and is commercially available through many vendors in the United States and internationally.

Advantages of SVE-based technologies often include:

- Minimize site disturbance.
- Treat large volumes of soil.
- Install quickly and easily at most sites.

TABLE 1 Summary of Soil Vapor Extraction Projects with Fully Defined Costs[a]

Site	Treated	Total Cost	Cost/yd^3 of Soil Treated	Cost/lb of Contaminant
Amcor Precast, Utah	TPH[b], BTEX[c]	$240,610	$32.08	NA[d]
Camp Lajeune, North Carolina	CVOCs[e], BTEX	$591,305	$35.79	NA
Commencement Bay, Washington	CVOCs	$4,477,689	$107.33	NA
Davis-Monthan Air Force Base, Arizona	CVOCs	$225,909	$3.59	$0.39
Richmond Superfund site, Virginia	CVOCs	$97,745	$102.64	NA
Fairchild Semiconductor Corporation Superfund site, California	CVOCs, BTEX	$4,442,609	$105.87	$277.66
Fort Lewis landfill site, Washington	CVOCs, metals	$1,623,250	NA	$27,054.16
Garden State cleaners, New Jersey	CVOCs	$197,009	$328.25	NA
Hastings Groundwater Contamination Superfund site, Nebraska	CVOCs	$456,862	$2.47	$761.44
Holloman Air Force Base, New Mexico	BTEX	$646,632	$68.07	$14.70
Intersil/Siemens Superfund site, California	CVOCs	$801,299	$2.68	$267.10
Kelly Air Force Base, Texas	TPH	$737,446	$82.86	NA
Rocky Mountain Arsenal Superfund site, Colorado	CVOCs	$212,399	$6.25	$3,034.27
Sacramento Army Depot Superfund site, California	VOCs, CVOCs	$677,417	$1,042.18	$294.27
Sacramento Army Depot Superfund site, California	CVOCs	$247,900	$2.09	$3,747.02
Sand Creek Industrial Superfund site, Colorado	CVOCs, TPH	$2,284,944	$72.68	$12.95
Shaw Air Force Base, South Carolina	TPH	$2,776,862	$33.32	$5.36
SMS Superfund site, New York	CVOCs, VOCs, TPH	$413,171	$63.54	NA
Twin Cities Army Ammunition Plant, Minnesota	CVOCs	$844,889	NA	$1.53
Underground storage tank site, Michigan	VOCs, TPH	$244,070	NA	$5.42
Verona Well Field Superfund site, Michigan	CVOCs	$1,753,833	$63.54	NA

Source: Adapted from D22449H.

[a]Remediation efforts have yet to be completed at some of the listed sites. Costs are adjusted to 1999 dollars. Please see D22449H for additional information.

[b]TPH, total petroleum hydrocarbons.

[c]BTEX, benzene, toluene, ethylbenzene, and xylene.

[d]NA, not available.

[e]CVOCs, chlorinated volatile organic compounds.

- Reduce VOCs in the vadose zone of the soil, decreasing the potential for contaminant migration.
- Complement groundwater treatment systems.

Limitations of SVE-based technologies often include:

- Subsurface heterogeneity can interfere with uniform airflow.
- Site permeability, clay content, depth to water table, and organic content can impact technology performance.
- Extracted vapors will often require the use of a treatment technology.
- Technologies may not be able to meet soil cleanup criteria.

Technology Cost

Soil vapor extraction is used to remove VOCs from soil. Since SVE does not destroy contaminants, it is most commonly used in a treatment train with other technologies such as granular activated carbon, thermal oxidation technologies, or scrubbing. Other technologies, including bioremediation, natural attenuation, air sparging, or fracturing, may be used to either increase the efficiency of SVE technology or treat residual contamination that may remain after SVE is used at a site. All of these factors will impact treatment costs (D22449H, p. 4–1).

Many site-specific factors can influence the cost of SVE treatment. Soil properties that can influence SVE costs include permeability, porosity, depth and stratigraphy of the contamination, site heterogeneity, and seasonal water table fluctuations. In general, the more permeable and homogenous the soil, the more efficiently SVE will operate, and the lower treatment costs will be (D22449H, p. 4–4).

Contaminant properties can also affect treatment costs. The type and amount of contaminants will impact the efficiency of SVE, the number of extraction wells, the power of the blower unit, and the length of operation required to achieve project goals. Contaminant properties will also impact the type of ancillary technology(ies) selected (D22449H, p. 4–4).

In 2001, the U.S. Environmental Protection Agency (EPA) published a cost analysis of various remediation technologies, including SVE. SVE technology costs were analyzed based on operation and maintenance (O & M) costs, capital costs, and other site-specific data (D22449H, p. 4–1). Cost data for these projects is summarized in Table 1.

In the cost analysis, EPA stated that there was a correlation between SVE unit costs and the volume of soil treated. SVE was demonstrated to have a measurable economy of scale. Unit costs for the treatment of less than 10,000 yd^3 of soil ranged from \$60 to \$350/yd^3. Unit costs for applications treating more than 10,000 yd^3 of soil were as low as \$5/yd^3 treated. A similar correlation was noted for unit costs versus mass of contaminants removed. Unit costs for projects with less than 3000 lb of contaminants requiring removal ranged from \$300 to \$900/lb. Unit costs for larger projects were less than \$15/lb, and costs for treating over 500,000 lb of contaminants were less than \$2/lb (D22449H, pp. 4–1, p. 4–4).

Information Source

D22449H, U.S. EPA, 2001

T0407

In Situ Steam-Enhanced Extraction — General

Abstract

In situ steam-enhanced extraction (ISE) combines steam injection and soil vapor extraction (SVE) to mobilize and remove organic contaminants from soil and groundwater. Steam, which

is injected into the subsurface, vaporizes volatile and semivolatile contaminants and displaces liquids in soil pores. This process is also known as steam stripping. Organic vapors and liquids are then pumped to the surface using extraction wells or trenches.

ISE is a commercially available technology. It has been implemented at sites contaminated with petroleum products (e.g., gasoline, diesel fuel, jet fuel) and solvents. The technology is capable of treating soil with underground obstructions such as buried tanks, utility lines, and buried rock and debris. This technology cannot remediate metals.

ISE technologies are available from multiple vendors. The RIMS library/database contains separate technology summaries for several ISE technologies:

Berkeley Environmental Restoration Center	Steam-Enhanced Extraction (SEE) (T0747)
Praxis Environmental Technologies, Inc.	In Situ Thermal Extraction Process (T0620)
SIVE Services	Steam Injection Vacuum Extraction (SIVE) (T0712)
Lawrence Livermore National Laboratory	Dynamic Underground Stripping (DUS) (T0748)
Hrubetz Environmental Services, Inc.	HRUBOUT® Process, In Situ (T0379)
TerraTherm Environmental Services, Inc.	Thermal Blanket for In Situ Thermal Desorption (T0784)
TerraTherm Environmental Services, Inc.	Thermal Wells (T0785)
Alternative Technologies for Waste, Inc.	Detoxifier In Situ Steam/Hot Air Stripping Unit (T0029)
CleanSoil Inc.	CleanSoil Process (T0168)
EM & C Engineering Associates	Grid Injection (T0245)
R.E. Wright Environmental, Inc.	Steam-Enhanced Recovery (T0638)
Western Research Institute	Contained Recovery of Oily Waste (CROW™) (T0881)

Technology Cost

At a contaminated site with soil concentrations of up to 5000 mg/kg and groundwater concentrations of approximately 60 mg/liter of chlorinated aromatics, ISE remediation took a fraction of the time compared to excavation and above-ground treatment. Although capital and operating costs were higher for ISE, cost savings of 30 to 50% were realized because of the reduced time for remediation (D10225Q p. 61).

Cost estimates range from about \$50 to \$300/yd^3 (\$65 to \$390/m^3) depending on site characteristics, particularly the depth of contamination and soil permeability. The more wells required per unit area (a function of contaminant depth), the higher the cost of remediation (D12529B).

The estimated cost of remediation of hydrocarbon-contaminated soils at the Lemoore Naval Air Station using the steam injection vacuum extraction (SIVE) technology is \$200 per ton (D12776O) (see Technology Summary T0712 for further information on SIVE).

The approximate total cost for remediation of a site with 95,000 yd^3 (73,000 m^3) of contaminated soil over a 2-year period was \$4,401,120, or \$46/yd^3 (\$60/m^3). Costs also were calculated for use of the steam-enhanced recovery process (SERP) at a similar site of the same size and contamination profile under what might be considered "typical" operation conditions. These costs were estimated to be about \$3,375,910, or approximately \$36/yd^3 (\$47/m^3) (D10949J, p. 37). Detailed cost estimates for SERP may be found in Section 3 of D10949J; see Case Study 1 in the reference for more information on the SERP demonstration that served as the basis for these costs.

Applications of ISE in deeper soils may realize a significant cost advantage over excavation, due to the difficulty in removing soils at greater depths. A minimum of contiguous waste is required for cost-effective operation. In general, SERP is not economical for areas smaller than 1000 ft^3 (93 m^2) or those with contamination extending to no more than 10 ft (3 m) below the soil surface (D10949J, p. 30).

Cost estimates for dynamic underground stripping (DUS), which incorporates ISE along with electrical soil heating, may be found in Technology Summary T0748.

Information Sources

D12529B, U.S. EPA, May 1991
D10225Q, Noonan et al., June 1993
D12776O, U.S. Navy, September 1996
D10949J, U.S. EPA, July 1995

T0408

In-Situ Fixation, Inc.

Dual Auger

Abstract

The Dual Auger™ system is an in situ treatment for soils contaminated with volatile organic compounds (VOCs), chlorinated volatile organic compounds (CVOCs), and inorganics. This process uses specialized equipment to mix soil and inject reagents. The system can add nutrients to promote bioremediation, inject steam to volatilize contaminants, install zero-valent iron to promote chemical treatment, or add a pozzolanic slurry to stabilize the contaminants. The injection and mixing process effectively breaks down fluid and soil strata barriers. Mixing also eliminates pockets of contamination that would otherwise remain untreated.

The patented Dual Auger system has been accepted into the Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration program. The technology has also been approved by the Arizona Department of Environmental Quality and demonstrated by the Department of Energy (DOE). Dual Auger is commercially available and has been used in full-scale applications.

Some advantages of the Dual Auger system are:

- Treats soil and groundwater in situ without excavation.
- Captures air emissions.
- Thoroughly mixes soil and maintains effective contact between treatment agents and contaminants.
- Operates in bedded soils with varying permeability.
- Treats soils in both vadose and saturated zones.
- Can focus treatment at a specific contaminated strata.

The efficiency of the system is dependent on the soil type, contaminant type, and contaminant concentrations. Many sites require that an impermeable barrier or containment wall be constructed to prevent the continued migration of pollutants through soil and water. The treatment area must be clear of underground obstructions. Treatment is generally limited to soil less than 40 ft deep. More energy may be required to achieve contaminant removal in saturated soils.

Technology Cost

According to the vendor, Dual Auger treatment costs range from \$15 to \$75/yd^3. In 1996, the *Oil & Gas Journal* stated that the average cost for treatment with the Dual Auger system was \$30 to \$50/yd^3 of soil. The vendor states that treatment costs vary based on waste handling and preprocessing requirements, initial and target contaminant concentrations, moisture content of the soil and other soil characteristics, depth to contamination, and amount of debris mixed with the waste (D22971U, p. 5; D12876R, p. 57).

In 1995, the Dual Auger/bioremediation technology was used at an automotive dealership in Yuma, Arizona. The $120,000 project remediated 2752 yd^3 of soil contaminated with diesel fuel and waste oil (D10314Q, p. 10; D12627C, p. 19).

A Dual Auger/steam stripping system was to treat 2048 yd^3 of saturated soil at the Pinellas Science, Technology, and Research (STAR) Center in Largo, Florida. Operating costs for the demonstration were approximately $13,000 per day. The treatment rate varied from 1 to 6 holes per day depending on the contaminant concentration. When the contaminant concentration was low, up to 6 holes were drilled per day, and treatment costs were approximately $50/$yd^3$. In areas of high contaminant concentration, the treatment rate fell to 1 hole per day, and the cost rose to $400 yd^3/day. Table 1 displays how the treatment cost varies with the treatment rate. These figures translate to treatment costs ranging from $300 to $500/lb of contaminant removed (D19687G; D18561Z; D22970T, p. 44). The total treatment costs for this demonstration are displayed in Table 2.

Information Sources

D10314Q, VISITT 4.0, undated

D12627C, Murray, 1996

TABLE 1 Variations in Treatment Cost Based on Treatment Rate

	Treatment Rate in Holes per Day					
Cost Factor	1	2	3	4	5	6
Volume per day (yd^3)	40	80	120	160	200	240
Volume treated in 60 days[a] (yd3)	2,400	4,800	7,200	9,600	12,000	14,400
Operating costs[b] ($/$yd^3$)	325	163	108	81	65	54
Mobilization/demobilization costs[c] ($/$yd^3$)	62	31	21	16	12	10
Total cost ($/$yd^3$)	387	194	129	97	77	64

Source: Adapted from D22970T.
[a]Based on volume treated per day.
[b]Based on $13,000 per crew-day.
[c]Based $2433 per day mobilization/demobilization costs and 60-day treatment period.

TABLE 2 Costs for Dual Auger Steam Stripping Project at Pinellas STAR Center

Action	Costs
Preproject operations visit	$2,400
Mobilization	$95,000
Monitoring, sampling, testing, and analysis	$59,000
Equipment	$468,267
Labor	$259,097
Supplies and materials	$25,250
Fuel	$21,037
Disposal of hydraulic oil	$200
Demobilization	$51,000
Total	$981,251

Source: Adapted from D19687G.

D12876R, Oil & Gas Journal, August 1996
D18561Z, Rice, 1998
D19687G, Federal Remediation Technologies Roundtable, 1998
D22970T, U.S. DOE, 1998
D22971U, U.S. EPA Reachit, undated

T0409

In-Situ Oxidative Technologies, Inc. (ISOTEC, Inc.)

ISOTEC

Abstract
ISOTEC™ is a technology that uses the periodic injection of hydrogen peroxide and proprietary catalysts to oxidize organic contaminants in situ. According to the vendor, this technology can treat soil and groundwater contaminated with chlorinated compounds, petroleum hydrocarbons, polychlorinated biphenyls (PCBs), trichloroethene (TCE), tetrachloroethene (PCE), pesticides, herbicides, as well as benzene, toluene, ethylbenzene, and xylene (BTEX). The ISOTEC technology is commercially available.

According to the vendor, ISOTEC has the following advantages over conventional Fenton-type treatment technologies:

- ISOTEC works at a neutral pH.
- ISOTEC catalysts prevent iron precipitation and iron fixation to soil, thus increasing the mobility of process reagents.
- The process includes stabilizers that increase the life span of the peroxide following injection.

The technology has several potential limitations. ISOTEC may not be effective at treating contaminants that are tightly adsorbed to soil particles. These compounds may include heavier aliphatics, polychlorinated alkanes, and some polyaromatic compounds. The process is also ineffective at treating free product, which must be removed prior to treatment with ISOTEC. Sites with a pH outside of a 2.5 to 8.5 range will require pH adjustments before using ISOTEC. In addition, ISOTEC may not be effective at sites where total organic carbon (TOC) content in soil is greater than 75,000 parts per million (ppm).

Because of the elevated iron concentration and low pH created by the ISOTEC process, regulatory approval may be required for some sites. The process can also create a temperature increase in the subsurface. According to the vendor, this increase can be as high as 10°C and lasts less than 24 hr.

Technology Cost
According to the vendor, ISOTEC can treat a contaminated site at less than half the cost of conventional technologies. The vendor also states that ISOTEC has no operation and maintenance costs (D17063I, p. 5). The following factors can influence full-scale treatment costs:

- Number of injection points
- Extent of soil and groundwater contamination
- Site geology
- Quantity of ISOTEC reagent required for treatment (D21464C, p. 6)

ISOTEC was used to treat groundwater at a warehouse site in Union County, New Jersey, from 1995 to 1996. Groundwater was contaminated with methyl tert-butyl ether (MTBE), as well as benzene, toluene, ethylbenzene, and xylene (BTEX). The total cost of this project, including pilot- and full-scale programs, was approximately $220,000. This cost includes chemical, injection, and sampling expenses. Pre-existing monitoring wells were used for sampling, so expenses associated with well installation are not included in the total cost (D18766A, pp. 5, 6).

Between 1996 and 1997, ISOTEC was used at a former sign manufacturing facility in Denver, Colorado. Project costs were approximately $200,000, including expenses associated with materials, injection, and sampling for the pilot- and full-scale programs. Pre-existing monitoring wells were used for sampling, so installation costs were not included (D18766A, pp. 4, 5).

ISOTEC was chosen to treat soils contaminated with dense non-aqueous-phase liquids (DNAPLs) at a Superfund site in Florida. With a projected cost of $340,000, ISOTEC was cheaper than the alternative technologies considered. The estimated cost for implementing six-phase heating at the site was $535,000, and the estimated cost for excavation and ex situ treatment was $835,000 (D21478I, pp. 10, 11).

Information Sources

D17063I, In-Situ Oxidative Technologies, Inc., undated

D18766A, U.S. EPA, 1998

D21478I, Swallow et al., 2000

D21464C, In-Situ Oxidative Technologies, Inc., undated

T0410

Institute of Gas Technology

AGGCOM

Abstract
The AGGCOM process is a two-stage fluidized-bed/cyclonic agglomerating combustor used for remediation of organics and inorganics in solid, liquid, and gaseous wastes.

AGGCOM combines and improves upon two technologies developed at the Institute of Gas Technology (IGT) over many years: fluidized-bed agglomeration/gasification and cyclonic combustion. The combustor destroys organic contaminants and encapsulates inorganic contaminants within benign, glassy agglomerates. Bench-scale test results were presented in 1991, and construction of a 6 ton/day pilot plant was completed in March 1993. Development of the process is continuing. This technology is not yet commercially available.

No literature describing continuous and uninterrupted soil agglomeration using the AGGCOM process is yet available.

Technology Cost
No information available.

T0411

Institute of Gas Technology

Fluid Extraction–Biological Degradation

Abstract
The Institute of Gas Technology's (IGT's) ex situ fluid extraction–biological degradation (FEBD) technology removes organic contaminants from soil, and then biologically degrades

the pollutants in aerobic bioreactors. The process combines three distinct technologies: (1) fluid extraction, which removes the organics from contaminated solids; (2) separation, which transfers the pollutants from the extract to a biologically compatible solvent or activated carbon carrier; and (3) biological degradation.

The FEBD technology effectively treats hydrocarbons (e.g., gasoline and fuel oils), non-halogenated aliphatic hydrocarbons, and polycyclic aromatic hydrocarbons (PAHs) such as naphthalene, phenanthrene, and benzo(*a*)pyrene.

Technology Cost
No available information.

T0412

Institute of Gas Technology

MGP-REM

Abstract
The MGP-REM technology, also known as chemical and biological treatment (CBT), was specifically designed to treat contaminants from manufactured gas plants (MGPs). This technology combines chemical oxidation using Fenton's reagent with aerobic biological degradation. Hydroxyl radicals, which are produced by Fenton's reagent, initiate a chain reaction with organic contaminants resulting in the degradation of organics into biodegradable forms. The technology has effectively treated soils and sludges contaminated with hazardous compounds including polynuclear aromatic hydrocarbons (PAHs), volatile hydrocarbons, and polychlorinated biphenyls (PCBs). The MGP-REM technology is commercially available and can be implemented either ex situ, for solid and slurry phase wastes, or in situ.

IGT has developed a treatability protocol for the MGP-REM technology to determine cleanup rates and the preferred mode of treatment (landfarming, soil slurry, or in situ). The protocol consists of three phases: Phase I is a feasibility test comparing a variety of techniques and is completed within 2 to 3 months; phase II is a bench-scale optimization under simulated field conditions; and phase III is the field-scale evaluation.

According to the vendor, studies conducted by IGT have determined the following:

- Bioremediation is effective in removing PAHs from MGP soils.
- Integrated chemical/biological treatment improves the rate as well as the extent of PAH removal.
- MGP soils can be effectively cleaned in the landfarming mode of the MGP-REM technology.
- Soils with high sand content are easier to clean with the technology.
- Integrated chemical/biological treatment is effective for soils with high silts and clay contents.

All information directly related to the technology is from the vendor and has not been independently verified.

Technology Cost
According to the vendor, the cost of site remediation using the in situ application of the MGP-REM technology is expected to range from \$30 to \$50/yd^3. Landfarming methods cost \$60/yd^3 while the cost of treatment in a slurry-phase bioreactor, including excavation, soil handling, soil processing, and treatment costs, is estimated at \$100 to \$150/yd^3 (D15751R, p. 4–6). In situ applications could range from \$25 to \$75/yd^3 (D214051, p. 3).

An economic evaluation was conducted from August 1993 to August 1994, by Remediation Technologies, Inc. (ReTech) under funding from the Gas Research Institute (GRI). The evaluation

TABLE 1 Cost ($) per Cubic Yard of Treated Wastes with 1, 2, and 5% Fenton's Reagent Solution for Enhanced Bioremediation

Process Area	1%	2%	5%
Estimate of Installed Facility Cost			
Prescreening and classification equipment	3.6	3.6	3.6
Soil washing and classification equipment	12.2	13.1	12.0
Bioslurry treatment equipment	30.6	23.8	23.2
Dewatering equipment	15.5	18.1	15.5
Site preparation/setup	12.9	12.9	12.9
Design and procurement	17.0	15.3	15.3
Total installed cost	91.6	86.6	82.3
Two-Year Project Operating Expenses			
Mobilization	3.7	3.4	3.4
Soil handling	10.3	10.3	10.3
Operation and maintenance	97.3	117.5	175.3
Demobilization	2.5	2.3	2.3
Operating expense total	113.8	133.5	191.3
Project total	205	220	274

Source: D15714M, Gas Research Institute, 1994.

compared the costs and remediation rates of "basic treatment" and the addition of Fenton's reagent. The basic treatment approach assumed that particles larger than 2 inches are considered clean and can be separated from the soil. Also, contaminants adhering to particles between 40 mesh and 2 inches in size will be reduced sufficiently by water washing and will not require biological treatment. The fine particles (<40 mesh) will be treated as a 25% water slurry in a bioslurry reactor. The Fenton's reagent study evaluated dosages of 1, 2, and 5% reagent in reactors. Table 1 gives a comparison of the capital and operating costs of the three reagent dosages. Compared to the basic treatment, use of the 1% reagent yielded costs that were $\$10/yd^3$ lower. The 2 and 5% Fenton's reagent treatments cost \$5 and $\$60/yd^3$ more than basic treatment (D15714M, p. vi, 7.6–7.9).

Treatment costs for the Vandalia MGP site in Des Moines, Iowa, were estimated to be \$50 to $\$70/yd^3$ of soil treated. In contrast, on-site incineration at most MGP sites is greater than $\$600/yd^3$. The Vandalia site was the first commercial-scale application of the MGP-REM technology (D214051, p. 2)

Information Sources

D15751R, Srivastava et al., 1995

D15714M, Gas Research Institute, 1994

D214051, Harju, 1998

T0413

Institute of Gas Technology

PCB-REM Process

Abstract

The PCB-REM process for the remediation of polychlorinated biphenyls (PCBs) in soils, sludges, and water uses both chemical and biological treatment. It is a combination of solids pretreatment

with surfactants, chemical oxidation using modified Fenton's reagent, and biological treatment using enriched bacterial cultures. All information is from the vendor and has not been independently verified. RIMS was unable to contact the vendor and thus the commercial availability of this technology is unknown.

Technology Cost
According to the vendor, the cost of the PCB-REM process is $250 to $400 per ton of soil (D15752S).

Information Source

D15752S, vendor literature

T0414

Institute of Gas Technology

SELPhOx

Abstract
SELPhOx is a supercritical extraction/liquid-phase oxidation process for removal and destruction of organic contaminants from soils and sludges. The process combines two processing steps: the supercritical fluid extraction (SCE) of organic contaminants and the wet-air oxidation (WAO) destruction of the extracted contaminants. The development of the SELPhOx process is proceeding from laboratory-scale experiments to testing of a transportable field test unit designed with a capacity of about 25 lb of soil per batch. Tests of the field unit are continuing.

SCE with carbon dioxide removes organic contaminants and leaves much of the original soil organic matrix in place. The contaminants are then collected on activated carbon in a contaminant collection vessel and transported in an aqueous stream to the WAO reactor for destruction. The concentration of the organic contaminants on activated carbon in water provides a suitable matrix for the WAO feed stream and allows for a smaller reactor size. The activated carbon is then regenerated in the WAO reactor with minimal carbon loss and can be recycled to the contaminant collection vessel.

The technology is not designed to handle metals.

According to the vendor, advantages of the technology include:

- SCE with carbon dioxide does not destroy the humic content of the soil; thus, clean soil can be returned to the site.
- Unlike incineration, SELPhOx generates no hazardous compounds such as dioxins and furans.
- SELPhOx is faster and more reliable than bioremediation processes.
- A primary gaseous emission from the WAO stage is carbon dioxide, which can be recycled to the SCE stage.
- Remediation costs are comparable to bioremediation (approximately $200 per ton).
- Contaminant removal and destruction levels can exceed 99%.

Technology Cost
Remediation costs are expected to be approximately $200 per ton; however, the technology is still in pilot-scale testing (D15144A, p. 721).

Information Source

D15144A, Mensinger et al., 1995

T0415

Institute of Gas Technology

Submerged Combustion Melting

Abstract
The Institute of Gas Technology (IGT) submerged combustion melting technology is an ex situ, natural-gas-fired combustion technology. The Gas Institute of the Ukrainian National Academy of Sciences (GI) used the principle of submerged fuel combustion to develop a compact, bubbling bath-type melting furnace that provides high production rates while using very little refractory. GI developed the technology to overcome problems associated with conventional technologies such as costly batch requirements, nonhomogeneous melts, large area requirements, and the production of high levels of combustion by-products.

The submerged combustion melting technology has potential applications in processes that produce glass melts from various feed materials (geological rocks, sand, waste slag, ash, etc.), in the manufacture of building materials, and in the treatment of industrial waste. The IGT submerged combustion melting technology has been used to produce mineral (silica) melts for the manufacture of thermo-insulation fibers, and supplementary cementitious materials (SCM) derived from specially designed waste blends combined with inexpensive natural materials.

The IGT submerged combustion melting technology is a commercialized, patented process (U.S. Patent 4,877,449), with the following advantages, according to the vendor:

- High thermal efficiencies that improve the homogeneity of the glass melt product
- Minimal refractory requirements
- Ability to handle nonhomogeneous feed sized up to 3 inches
- Compact size
- Easy startup and shutdown
- Low gas-phase emissions
- Uses inexpensive and clean natural gas fuel
- Capacity for solids recycle

Before the submerged combustion melter can operate successfully, stable combustion of the fuel within the melt must be achieved. The injection of a combustible mixture into a melt results in the formation of cold channels, leading to explosive combustion and excessive melt fluidization.

Technology Cost
No available information.

T0416

Intech One-Eighty

White-Rot Fungus

Abstract
Intech One-Eighty has researched the use of white-rot fungus to degrade organic contaminants in soils, sludges, and sediments. White-rot fungi are a group of naturally occurring organisms that obtain nutrients through an enzyme reaction that degrades lignin, a structural component of

wood. The enzymes secreted by these organisms are nonspecific and have been shown to degrade many recalcitrant organic contaminants, such as polycyclic aromatic hydrocarbons (PAHs), pentachlorophenol (PCP), dioxins, furans, pesticides, and explosives. The Intech One-Eighty white-rot fungus is generally applied in treatment cells as an on-site, ex situ process. According to the vendor, it may also be used as an in situ technology in some situations.

Utah State University holds multiple patents for the destruction of environmental contaminants using white-rot fungus enzymes. Intech One-Eighty is the exclusive licensee of these patents. Other firms have sublicensed the technology through Intech One-Eighty, including McLaren Hart, Inc., Heritage Environmental Services, EarthFax Engineering, Inc., Biotal Ltd. (UK), and WithWaste Co. (Japan). The white-rot fungus process is a field-tested, commercially available technology.

The white-rot fungus treatment technology has the following advantages:

- Extracellular breakdown mechanism used by white-rot fungus allows it to treat a wider range of contaminants than bacterial degraders.
- White-rot fungus can survive in environments considered biotoxic.
- Fungus enzymes are produced as long as substrate is present, thus fewer contaminant residuals remain after treatment (compared to bacterial degradation).
- White-rot can treat complex combinations of contaminants.

Intech One-Eighty's white-rot fungus technology can be limited by certain environmental conditions. For example, extreme moisture levels can create potential problems for bioremediation using fungi. In some cases, sites may need protection from heavy precipitation, while extra measures must be taken to conserve moisture in dry areas. Buffering agents may also be required in locations where groundwater and surface water contamination are combined, or where wastes are highly acidic.

Technology Cost

A full-scale demonstration of white-rot fungus treatment was conducted in Brookhaven, Mississippi, as part of the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) program. The purpose of this study was to generate economic data for the technology. Costs of the fungal treatment operation were estimated at \$150 to \$200 per ton of soil treated. Lower costs may be achieved with new inoculum formulations, which would allow for a reduction in the amount of inoculum mass needed for treatment (D188356).

EarthFax Engineering, Inc.'s, version of the Intech One-Eighty process was tested by the U.S. Army on tetryl-contaminated soils. Based on bench- and pilot-scale studies, the cost of treating 10,000 yd^3 of soil to a tetryl concentration of 250 parts per million (ppm) was estimated to be \$1792/yd^3. The cost of treating 50,000 yd^3 was estimated at \$849/yd^3, and the cost of treating 100,000 yd^3 was estimated at \$804/yd^3 (D221476, p. 3).

Information Sources

D188356, U.S. EPA, undated
D221476, U.S. Army, undated

T0417

Integrated Chemistries, Inc.

Capsur

Abstract

Capsur® is an aqueous-based solvent system developed specifically for the cleanup of polychlorinated biphenyl (PCB) spills on solid surfaces, including concrete, asphalt, and metal.

Capsur can also be applied as a foam to overhead, vertical, and horizontal surfaces. Capsur is commercially available.

Capsur interacts chemically with the PCB molecule allowing extraction of PCBs from surfaces and then suspends the PCBs in water allowing their removal. Capsur is applied, allowed to dwell on the surface for approximately 5 min and is then vacuumed off. This process is repeated as necessary until the concentration reaches the target.

The prior use of kerosene or other solvents in PCB spill cleanup activities may interact with the substrate and increase the migration of PCBs into the contaminated media making removal more difficult. Painted surfaces should be patch tested prior to application as paint softening or discoloration may occur.

According to the vendor, Capsur's advantages include a high extraction rate, lower labor costs, usefulness on new and old spills, and a wide applicability.

Technology Cost

A 5-gal container [national stock number (NSN) 6850-01-423-1059] of Capsur costs $240.00 ($48.00/gal). A 55-gal container (NSN 6850-01-423-1061) costs $2475.00 ($45.00/gal). Cost information is from the 1997 price list (D15272H).

According to the vendor, Capsur's extraction efficiencies allow for less product use and fewer applications than for competitive products, resulting in lower labor costs. Average coverage rates given by the vendor (D15272H) are as follows:

- Porous concrete = 125 ft^2/gal
- Asphalt = 175 ft^2/gal
- Metals = 200 ft^2/gal

Note that multiple applications may be required to achieve target cleanup levels (D14277I).

The Model T Jr. Foamer, the cleaning system sold by Integrated Chemistries, Inc., for application of Capsur, costs $2900.

Information Sources

D14277I, vendor information

D15272H, vendor information and price list

T0418

Integrated Chemistries, Inc.

Metraxt

Abstract

Metraxt™ is an aqueous system developed to clean up metals on solid surfaces. Metraxt can be applied as a foam blanket that allows application to overhead, vertical, and horizontal surfaces. This technology is formulated to extract heavy metals from concrete, asphalt, and metal surfaces by bonding with them.

This technology is currently commercially available.

According to the vendor, benefits of Metraxt include the following:

- High extraction rate
- Lower labor cost
- Successful on new and old spills

The application coverage of Metraxt will vary with surface porosity and operator efficiency. The coverage for porous surfaces is 100 ft^2/gal, and for nonporous surfaces it is 125 ft^2/gal. This material may be corrosive to some metal surfaces and painted surfaces.

If the concentration of metal contaminant is very high, the spill is old, or the site has a history of spills, multiple applications of Metraxt will be necessary to get acceptable results. It is not uncommon when analyzing before and after the first few treatments to get higher readings due to the product's ability to extract metals from solid surfaces.

Because of the chemical activity of Metraxt, the equipment used for application and vacuuming requires routine inspection and maintenance. Hoses and gaskets will have to be periodically inspected. Washing the foamer, its hoses and gaskets with soap and water and rinsing with water is recommended after each use to extend lifetime.

Technology Cost

The estimated cost for Metraxt is $0.20 (1997 dollars) per square foot of treated area. These estimates do not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals.

Factors that have a significant effect on unit price include the following:

- Initial contaminant concentration
- Depth of contamination
- Condition and age of the surface (D10313P, p. 13)

According to the vendor, a 5-gal container [national stock number (NSN) 6850-01-417-1850] of Metraxt costs $33 (1997 dollars) per gallon, and a 55-gal container (NSN 6850-01-417-1812) costs $29 (1997 dollars) per gallon. A Model T Jr. Foamer (15-gal unit) costs $2900 (1997 dollars). One gallon of Metraxt will clean 100 ft^2 for porous surfaces and 125 ft^2 for nonporous surfaces (D14067A).

Information Sources

D10313P, VISITT Version 4.0, 1995

D14067A, Integrated Chemistries, Inc., vendor literature, 1991

T0419

Integrated Chemistries, Inc.

Pentagone

Abstract

Pentagone is an aqueous-based surface decontamination product developed for the cleanup of pentachlorophenols, creosote, petroleum hydrocarbons, chlorinated hydrocarbons, polynuclear aromatic hydrocarbons, and selected pesticide and herbicide spills. It can be used on concrete, asphalt, or metal and is capable of being applied as a foam, allowing treatment of overhead, vertical, and horizontal surfaces. It has been commercially available since 1993 and has been used in multiple applications.

Pentagone is sprayed or foamed onto the contaminated surface and allowed approximately 5 min dwell time. It is then rinsed with clean water and vacuumed from the surface. This process is repeated until the surface reaches target contaminant levels.

According to the vendor, Pentagone will achieve superior extraction efficiencies that will result in less labor, product usage, and hazardous waste. These features lead to a lower overall

project cost when compared to traditional decontamination technologies such as high-pressure water blasting, shot blasting, and scabbling.

Technology Cost
Pentagone is available in 5-gal containers [national stock number (NSN) 6850-01-428-6502] for $165.00 ($33/gal) or 55-gal containers (NSN 6850-01-428-6500) for $1595 ($29/gal). These costs are based on 1997 pricing (D14636L, p. 19).

Information Source

D14636L

T0420

Integrated Environmental Solutions, Inc.

Quick-Purge

Abstract
Quick-Purge™ is a patented, commercially available, in situ technology for the remediation of soil and groundwater contaminated with organic compounds. The technology is primarily used for the remediation of sites contaminated with hydrocarbon constituents associated with diesel fuel, gasoline, kerosene, solvents, and creosote.

According to the vendor, Quick-Purge technology uses pressurized gas to strip contaminants from the subsurface, resulting in faster remediation than traditional soil vacuum extraction (SVE) or pump-and-treat technologies. The system design can also be used to deliver gases or liquids to the subsurface for bioremediation or stabilization of inorganic species.

Technology Cost
The vendor claims that Quick-Purge costs up to 50% less than traditional remediation methods such as pump-and-treat or soil vacuum extraction (D14386M).

Table 1 presents some representative vendor-supplied remediation costs.

TABLE 1 Cost of Remediation Using Quick-Purge

Site	Area (ft^2)	Media	Duration[a] (days)	Cost of Remediation
Closed convenience store	3,100	Groundwater and fine to silty sand within vadose zone	30	$102,200
Abandoned fuel oil wholesaler	3,503	Groundwater	9	$120,000
Bus fueling and repair facility	3,012	Groundwater	7	$70,000
Convenience store	2,800	Groundwater and soil—clayey sands	3	$30,000
Vacant residential land	10,570	Groundwater	14	$268,000
Convenience store	7,000	Groundwater and soil—fine to silty sand	21	$100,000

Source: Adapted from D14383J.
[a]Duration is the length of time Quick-Purge was used and does not include follow-up monitoring.

Information Source

D14383J, Integrated Environmental Solutions, Inc., date unknown

T0421

InterBio

Hydrobac

Abstract
Hydrobac® is designed to remediate waste treatment systems consisting of oil field and refinery wastes, oil sludge farming operations, and spill cleanup situations. The vendor indicates that this technology can treat wastes resulting from pumping, distilling, fractionation, alkylation, and polymerization processes. The wastes from these processes are usually of large volume containing high suspended and dissolved solids, oil, wax, sulfides, mercaptans, phenolic compounds, cresylates, and other hydrocarbon-based compounds. The vendor claims that cyanides are biologically removed from solution.

All information is from the vendor and has not been independently verified. This technology is not currently offered by InterBio®.

Technology Cost
There is no available information regarding the costs associated with this technology.

T0422

InterBio

Petrobac

Abstract
Petrobac® is a microbial technology designed to degrade crude oil or refined hydrocarbons in saline environments. According to the vendor, it can also be used to treat waters with salinity levels greater than 2%. InterBio® states that the technology has been used to remediate oil spills on surface water and surrounding beaches in marine environments as well as various hydrocarbons in other saline conditions. The vendor claims that Petrobac's bacteria are capable of consuming crude oils as well as products from crude oil processing (i.e., organic acids, alcohols, aldehydes, ketones, esters, and other chemical intermediates). Additional applications include degradation of crude and processed oil in soil, sand, and wastewater as well as remediation of residues in tanks and pipelines.

All information is from the vendor and has not been independently verified. According to the vendor, this technology is no longer available from InterBio.

Technology Cost
No available information.

T0423

InterBio

Phenobac

Abstract
Phenobac® is a commercially available biodegradation technology designed to treat industrial and manufacturing hydrocarbon waste discharges. The technology can be used for pretreatment

or complete on-site treatment systems and in municipal systems receiving mixed wastewater from community activities. Typically it is used to remediate industrial and manufacturing hydrocarbon waste discharges from chemical plants, steel mills, textile, and food processing plants. According to the vendor, this technology degrades organic wastes that contain complex organics, such as phenols, benzenes, aliphatic and aromatic hydrocarbons, methacrylates, nitriles, creosols, napthalene, amines, organic alcohols, synthetic detergents and surfactants, gasoline, kerosene, fuel, and machine oils.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0424

IET, Inc.

Barrier System

Abstract
The IET barrier system is a patented, commercially available in situ technology for the diversion and collection of contaminated groundwater or the confinement of contaminated soil. The IET barrier can be constructed as a boom around a portion of the contaminated area or as a bottomless "tank." Barriers consist of a high-density polyethylene (HDPE) liner or thick steel sheet pile with a patented locking mechanism. Collection reservoirs are installed adjacent to the barrier and can be used to treat contaminants in place or to pump contaminated groundwater to the surface for treatment.

According to the vendor, the technology has the following advantages: It does not require extensive excavation or movement of contaminated soils; it allows remediation to be performed in fully saturated subsoils that would preclude excavation; and using the technology for a number of separate sequential treatment strategies reduces the capital and operating costs to complete a total site remediation.

Intermittent rock layers or ledges would restrict the cost effective installation of the IET barrier. In addition, the installation of the IET barrier in caving sands or gravel is difficult and in some cases possible only to a depth that shoring will allow. Epoxy-coated and sealed joint sheet pile may be used to create the barrier in instances where sand and gravel are a problem.

All information is from the vendor and has not been independently verified.

Technology Cost
The costs were provided by the vendor for a treatment system using IET barrier with Biodrain (T0425) for in situ bioremediation. In 1992, remediation costs using this method were estimated to be between \$35 and \$40/yd^3 of waste treated. Depth of contamination and quantity of waste were cited as being the most important factors affecting price (D15333D, p. A-8).

Information Source

D15333D, IET, 1992

T0425

International Environmental Technologies (IET), Inc.

Biodrain

Abstract
The Biodrain system is a patented, commercially available, in situ technology for the collection and treatment of biodegradable contaminants in soil and groundwater. The Biodrain system

consists of permeable wicks installed to collect contaminated groundwater or supply microorganisms, oxygen, and/or treatment chemicals to the contaminated area. According to the vendor, this technology can also be used for the mobilization or immobilization of metal contaminants and is applicable to volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and total petroleum hydrocarbons (TPH).

Bioremediation using Biodrain is not possible for compounds resistant to biodegradation. Much longer degradation times are required for compounds such as polychlorinated biphenyls (PCBs) and polynuclear aromatics (PNAs); 3 to 7 years may be required for highly resistant contaminants. Bioremediation is also limited by below-freezing temperatures and free aqueous metals concentrations. Metals can be extracted or immobilized prior to biotreatment. Biodrain cannot be installed in rock or some landfill situations unless holes are drilled first. Current installation limits are approximately 40 ft.

Technology Cost

The costs were provided by the vendor for a treatment system using International Environmental Technologies (IET), Inc., barrier (T0424) with Biodrain for in situ bioremediation. Remediation costs using this method were estimated to be between \$35 and \$40/yd^3 of waste treated in 1992. Depth of contamination and quantity of waste were cited as being the most important factors affecting price (D15333D, p. A-8).

Information Source

D15333D, IET, 1992

T0426

International Environmental Trading Company, Inc.

Metals Extraction and Recycling System

Abstract

International Environmental Trading Company (IETC) has developed the Metals Extraction and Recycling System ™ (MERS™) technology (formerly Mercury Extraction Recovery System™) for the ex situ treatment of metals-contaminated soils and sediments. IETC states that this system is unique because specific metals can be targeted for extraction, leaving other metals in the soil; targeted metals are discharged in a 50 to 99% concentrated form; and all soil is remediated on-site, eliminating the need to transport soil backfill or manage off-site wastes. According to the vendor, the advantages of the system are that using MERS terminates the owner's long-term liability, there is no need for backfill soil, and metals are recovered in a concentrated form suitable for recycling.

This process only treats metal contaminants. IETC states that each metal has its own "recipe" that must be adjusted for various concentration levels. Bench-scale treatability studies must be carried out before starting treatment. Among site conditions that may affect process operation and economics are concentration of target metals, concentration of soluble metals, total metal concentration, pH, alkalinity, and particle size distribution.

Technology Cost

Costs for MERS are price dependent. In October 1996, IETC estimated that the cost of treating soil and sediment to remove lead ranged from \$125 to \$175/ton (\$138 to \$193/metric ton). These averages were for waste volumes between 5000 and 15,000 tons (4500 to 14,000 metric tons).

Larger volumes of waste can be treated at lower costs. According to IETC, costs for drummed wastes are assigned on a per-drum basis.

Pricing for treating mercury-contaminated soils was estimated at \$400 to \$750/ton (\$440 to \$830/metric ton). On-site treatment of mercury is economical if soil volumes exceed 3000 yd^3; for lower soil volumes, transport of the soil to a fixed facility is recommended. The IETC fixed facility accepts bulk soil shipments and drummed wastes (D12766M).

The vendor states the cost of full-scale MERS treatment depends on soil characteristics, the concentration and chemical state of the targeted metal contaminants, the concentration of unregulated metals, and the cleanup objectives. The vendor claims the cost of MERS processing is competitive with the cost of landfill disposal, soil stabilization, and soil washing (D124538, pp. 1444–1445).

Information Sources

D124538, Burson and Elston, 1994

D12766M, International Environmental Trading Company, 1996

T0427

International Landmark Environmental, Inc.

Aminoplast Capillary Technology

Abstract

The International Landmark Environmental, Inc., Aminoplast Capillary Technology (ACT) is an absorbent product for hydrocarbon and petroleum-based liquids. It can be used for contamination in soil or on surfaces, including liquid surfaces because the material is hydrophobic (will not absorb water) and floats. According to the vendor, ACT also has bioremediative characteristics, acting as a slow release fertilizer, encouraging microbe growth for the break down of toxic waste liquids.

ACT is commercially available and according to the vendor has been used in full-scale applications in multiple applications in numerous countries.

The absorbent may be susceptible to long-term ultraviolet (UV) exposure. All information was provided by the vendor and could not be independently verified. This technology is not designed for use with metals.

Technology Cost

Cost information comes from a vendor-supplied comparison of ACT and clay-type products. The example used was a 55-gal spill (440 lb). A spill of this size would require 880 lb of clay or 7.3 lb of ACT. At \$0.10/lb for clay, the material cost would be \$88, while ACT costs \$9.50/lb with a total material cost of \$85.50. Transportation cost of the materials was estimated by Landmark to be \$1.50/lb. Once the materials have absorbed the 440 lb of contaminant, the weights increase to 1320 lb (clay and contaminant) and 447.3 lb (ACT and contaminant), and therefore respective shipping costs become \$1980 and \$670.95 to transport the "full" absorbents. Adding the material and shipping costs required for this 55-gal spill, total costs for clay-type absorbents is \$2878 and ACT is \$1026.45. These prices are based on 1996 information (D16319J, p. 9).

Information Source

D16319J, vendor literature, 1996

T0428

International Landmark Environmental, Inc.

Diatomite

Abstract
International Landmark Environmental, Inc.'s (Landmark's), diatomite is a filtration media for removal of metallic, organic, and low-level radioactive nuclear contaminants from liquid waste streams. In July, 1996 Landmark was awarded an exclusive worldwide distribution contract for diatomite mined from the Pozzolanic Deposits near Hallelujah Junction, Lassen County, California. The diatomite is to be extracted by the American Pozzolan Corporation. According to the vendor, Landmark was considering technology associations with various organizations for the implementation of Landmark diatomite in existing and future filtration technologies. As of 1998, this technology was no longer available from Landmark.

The Landmark diatomite material is treated and processed to a purity and grade that will collect angstrom-sized particles. According to the vendor, because of the diversity and shapes of the diatoms, different blends may be formulated to filter out almost any kind of material from a liquid including heavy metals, organics, and radionuclides from low-level waste streams of nuclear installations.

All information was provided by the vendor and could not be independently verified.

Technology Cost
No available information.

T0429

International Process Systems, Inc.

High Force Magnetic Separators

Abstract
Magnetic separation is an ex situ physical separation technology that removes plutonium from contaminated soils. Magnetic separation works on the basis of differences in magnetic susceptibility. When particles encounter a strong magnetic field, those with an overall positive magnetic susceptibility (i.e., that are paramagnetic) are attracted toward the highest field gradient while those with an overall negative magnetic susceptibility (those that are diamagnetic) are repelled from the highest field gradients. This phenomenon is the basis of physical separation. International Process Systems, Inc. (INPROSYS), offers both wet and dry process separators including High Force™ magnetic roll separators, High Force magnetic drum separators, and wet high-intensity magnetic separators (WHIMS).

This technology is currently commercially available.

The type of waste feed has an effect on separator performance. Results of treatment of different types of wastes have yielded considerable differences in separation efficiencies. These differences can be attributed to variations in magnetic susceptibilities of the host materials and physical attachment of the plutonium to the residue.

Technology Cost
No available information.

T0430

ISOTRON Corporation

Electrokinetic Decontamination Process

Abstract
ISOTRON® Corporation's electrokinetic decontamination process is a patented, in situ process for the removal of contaminants from soil, groundwater, and porous concrete. The technology applies a low-intensity direct current (DC) across electrode pairs to facilitate electromigration and electro-osmosis of contaminants. The process works primarily on highly soluble ionized inorganics including alkali metals, chlorides, nitrates, and phosphates. Heavy metals such as lead, mercury, cadmium, and chromium have also responded favorably.

The technology is commercially available for the decontamination of soil and porous concrete but is still being developed for the decontamination of water.

ISOTRON's ELECTROSORB® "C" technology applies an electric field to induce migration of ionic contaminants from within porous concrete. This process provides an in situ alternative to concrete decontamination, thereby eliminating physical or mechanical damage of the concrete and allowing reuse of the structure or facility. The process generates minimal secondary waste and no airborne particulates common to conventional scabbling or physical abrasion techniques.

According to the Interstate Technology and Regulatory Cooperation Work Group, the electrokinetic decontamination process has the following advantages:

- May be able to treat soils not accessible for excavation.
- Applicable in soils with low permeability and high clay content.
- Treats inorganic and organic contaminants.
- Is cost effective.

Heterogeneities or anomalies in the soil will reduce removal efficiencies. Extreme pHs at the electrodes may inhibit the system's effectiveness. The electrokinetic remediation process is limited by the solubility of the contaminant, the desorption of the contaminants from the soil matrix, and reduction–oxidation changes induced by the electrode reactors. Electrokinetic remediation requires sufficient pore water to transmit the electrical charge. Contaminant and noncontaminant concentrations effect the efficiency of the process.

Technology Cost
Based on 1996 testing of the ELECTROSORB process for the U.S. Department of Energy (DOE), the vendor estimates the cost of concrete decontamination to be $4.91/ft^2. Costs square foot are broken down in the following manner: disposal costs $2.51, capital costs $1.15, chemical costs $0.67, labor costs $0.52, vaporization energy $0.033, and electrical costs $0.03. This estimate is based on cleanup of 600 ft^2 and involves the following components:

- Thirty extraction pads
- Three circulation and processing units
- Capital costs based on a 3-year life span
- System operating 100 days/year
- Two-person crew at $43.75 per hour
- secondary waste disposal rate of $300/ft^3
- Electricity cost of $0.08/kWh (D17274R)

Disposal costs are estimated for hazardous waste. The vendor states that the disposal costs for secondary radioactive waste disposal will be significant (D17274R, p. 13).

Costs for electroremediation were estimated by some researchers to be $90 to $130 per ton of treated waste in 1994, a price range similar to or lower than conventional remediation methods such as soil vapor extraction (D131657, p. 289).

According to the Interstate Technology and Regulatory Cooperation Work Group, the cost of electrokinetic remediation is dependent on specific chemical and hydraulic properties of the soils present at the site. Initial and target contaminant concentrations, concentration of nontarget ions, conductivity of pore water, soil characteristics, moisture content, quantity of waste, depth of contamination, residual waste handling and processing, site preparation requirements, and electricity and labor rates also have a significant effect on the unit price of electrokinetic remediation (D19938G, pp. 16, 17).

Information Sources

D131657, Trombly, June 1994

D17274R, Lomasney et al., undated

D19938G, Interstate Technology and Regulatory Cooperation Work Group, 1997

T0431

IT Corporation

Batch Steam Distillation and Metals Extraction

Abstract

The batch steam distillation and metals extraction treatment process is a two-stage technology that treats soils and sludges contaminated with organics, inorganics, and heavy metals. According to the vendor, steam distillation removes volatile organics from an aqueous slurry of the contaminated soil. The steam distillation vapors are condensed, cooled, and decanted to separate organic contaminants from the aqueous phase. Organic contaminants either undergo secondary treatment or they are disposed of off-site. The soil slurry is then extracted with hydrochloric acid to remove metals.

The vendor claims the following advantages for this technology:

- Uses simple equipment.
- It is not affected by soil moisture content.
- Adjustments are easy to implement for changes in soil characteristics.
- Scale-up is direct and uncomplicated.
- Air emissions are minimized and easily controlled.
- Excess reagents can be easily recovered.

As a batch process, this technology is limited to sites with less than 5000 tons of soil needing treatment. Processing time depends on equipment size and batch cycle times. In addition, some waste contaminants can cause foaming of the slurried soil during the batch steam distillation step requiring antifoaming agents or reduced steam rates.

Technology Cost

The estimated treatment costs per ton, including capital recovery, for the batch steam distillation are $299 to $393/ton and $266 to $350/ton at a 500-ton site and a 2500-ton site, respectively.

The metal extraction step, including acid recovery, is $447 to $619/ton and $396 to $545/ton for a 500-ton site and a 2500-ton site, respectively (D108178, p. 2).

Information Source

D108178, U.S. EPA, 1995

T0432

IT Corporation

Below-Grade Bioremediation

Abstract

Below-grade bioremediation is an ex situ technology designed to treat soil, sludge, and sediment impacted with chlorinated cyclodiene insecticides such as chlordane and heptachlor. Naturally occurring fungi are added to pesticide-contaminated soil, which is then treated in a below-grade actively aerated bioremediation cell.

All information is from the vendor and has not been independently verified. The commercial status of this technology is unknown.

Technology Cost

No available information.

T0433

IT Corporation

BIOFAST

Abstract

BIOFAST™ is IT Corporation's (IT's) patented forced-air soil treatment system that stimulates the production of biodegrading bacteria by supplying oxygen, nutrients, and moisture to contaminated soils. BIOFAST systems can be constructed aboveground or placed in excavated bioremediation "pits." These bioremediation systems are constructed by alternately layering gravel with a mixture of nutrients and contaminated soil, covering to reduce drying, and aerating to ensure adequate aerobic conditions for biodegradation.

BIOFAST is particularly suited for treatment of semivolatile and nonvolatile organic compounds, including biodegradable total petroleum hydrocarbons, halogenated compounds, pesticides, propellants, and polycyclic aromatic hydrocarbons. However, controlling volatile emissions and sampling and analyzing soils during the application of this technology can be difficult.

Technology Cost

The vendor of this technology claims the cost of BIOFAST is typically between $25 and $75/yd^3 of soil ($32 to $98/m^3). Price estimates may not include the costs of excavation, permits, treatment of residuals, or other indirect costs. The following factors may influence price:

- Initial contaminant concentration
- Site preparation
- Target contaminant level
- Preprocessing

- Soil quantity to be treated
- Amount of debris
- Depth of contamination
- Depth to groundwater
- Utility/fuel rates
- Volatile emissions (D10306Q, D121926).

Information Sources

D10306Q, VISITT, July 1995
D121926, IT Corporation, 1996

T0434

IT Corporation

Biological Polishing Treatment

Abstract
IT Corporation performed laboratory-scale testing of the use of micronutrients from yeast extract to encourage biological polishing after thermally enhanced fluid injection with vacuum extraction (FIVE) for coral sand contaminated with petroleum hydrocarbons. The commercial availability of this technology is unknown.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0435

IT Corporation

Chelation/Electrodeposition of Toxic Metals from Soils

Abstract
IT Corporation conducted laboratory-scale research on an ex situ technology known as chelation/electrodeposition of toxic metals from soils. The technology removes heavy metals from contaminated soils and sludges by forming a soluble chelate. The metal and chelating compound are then separated from the soils and recovered. The technology is potentially applicable for treating a wide range of metal-contaminated hazardous wastes, including soils and sludges. This technology is not currently commercially available.

Technology Cost
No available information.

T0436

IT Corporation

Direct Application of Surfactants

Abstract
IT Corporation (IT) conducted a critical evaluation of the direct application of surfactants to petroleum-contaminated soil to increase biological removal of the hydrocarbons. The technology

was tested at laboratory scale, and the results suggested that the application of surfactants directly to the soil was not successful in achieving greater levels of petroleum hydrocarbon removal. Due to these results, the technology has not been demonstrated further and is not commercially available.

The direct application of surfactants is a technique to enhance land treatment technologies, sometimes also known as landfarming. In this treatment scenario contaminated soil is spread on lined, bermed plots where it is treated with nutrients to encourage microbial growth, aerated periodically through tilling, and other parameters are monitored, such as pH and soil moisture. The direct application of surfactants was suggested to increase availability of the hydrocarbons in the soil and thereby increase biodegradation.

The increase in microbe populations that can be caused by direct application of surfactants leads to an increased need for oxygen (an increase in the biological oxygen demand, or BOD). This increased demand for oxygen was handled in a laboratory-scale experiment where the soil was easily mixed each day for aeration; however, it was implied that oxygen could act as a limiting factor in a full-scale application where aeration would be more difficult.

The large-scale use of surfactants in land treatment systems should be carefully evaluated, considering the results of the IT study, which showed no apparent benefits of direct surfactant application.

Technology Cost

In a 1991 investigation of direct application of surfactants to petroleum-contaminated soil, IT found that to make the technology work required a large amount of surfactant, which drove the price up. It determined that the costs did not justify the benefit and decided not to pursue the technology further (personal communication, Duane Graves, 1/2/97).

Full-scale land treatment, of the type where surfactant might be applied, typically cost between $30 and $70. Table 1 illustrates the approximate additional costs associated with the direct application of surfactants to 2500 lb/yd^3 of soil. All information is as of 1991 (D15468R, p. 165–166).

Information Source

D15468R, Graves and Leavitt, 1991

TABLE 1 Additional Costs of Direct Application of Surfactants to 2500 lb of Soil

Surfactant Cost ($/lb)	Surfactant Rate (weight/weight)	Surfactant (lb/yd^3)	Additional Cost ($/yd^3)
$0.50	1.0%	25	$12.50
$1.00	1.0%	25	$25.00
$1.50	1.0%	25	$37.50
$2.00	1.0%	25	$50.00
$2.50	1.0%	25	$62.50
$3.00	1.0%	25	$75.00
$0.50	0.5%	12.5	$6.25
$1.00	0.5%	12.5	$12.50
$1.50	0.5%	12.5	$18.75
$2.00	0.5%	12.5	$25.00
$2.50	0.5%	12.5	$31.25
$3.00	0.5%	12.5	$37.50

Source: Adapted from D15468R.

T0437

Fluor Daniel GTI, Inc.

Engineered Bioremediation System

Abstract

The engineered bioremediation system (EBS) is a proprietary process for the ex situ bioremediation of organic contaminated soils. The system is designed to enhance the natural bioremediation rate of organic constituents by controlling factors affecting microbial growth and metabolism.

The original vendor, Groundwater Technology, Inc., recently merged with Fluor Daniel's environmental division, forming Fluor Daniel GTI, Inc.

Heavily chlorinated organic wastes may reduce the performance of this technology. The waste must be biodegradable for use of this technology. All information is from the vendor and has not been independently verified.

Technology Cost

The vendor estimates the cost of this technology from \$40 to \$200/yd^3 (D10082T, p. 35).

Information Source

D10082T, VISITT 4.0, 1995

T0438

Fluor Daniel GTI, Inc.

Enhanced Natural Degradation (END)

Abstract

Enhanced natural degradation (END) is an in situ bioremediation technology for groundwater contaminated with hazardous organic compounds. By promoting the proper environmental conditions, the natural microorganisms in the subsurface soils multiply and transform the contaminants into nontoxic compounds, according to the vendor.

The original vendor, Groundwater Technology, Inc., recently merged with Fluor Daniel's environmental division, forming Fluor Daniel GTI, Inc.

The performance of the system will not be optimal for wastes containing heavily chlorinated organics. Wastes must be biodegradable to be treated by this technology. All information is from the vendor and has not been independently verified.

Technology Cost

The vendor estimates the cost of this technology from \$30 to \$60/yd^3 (D10084V, p. 24).

Information Source

D10084V, VISITT 4.0, 1995

T0439

IT Corporation

Fluid Injection with Vacuum Extraction (FIVE System)

Abstract

The fluid injection with vacuum extraction (FIVE system) technology uses injection wells to extract volatile organic compounds (VOCs) (generally resulting from a spill) from groundwater

and saturated soil. The closed fluid circulating system uses injection fluid in the form of liquid or gases (inert gas such as nitrogen). The gas is either injected or allowed to flow into the subsurface at locations around a spill site. The vapor-laden gas is then withdrawn under reduced pressure from recovery or extraction vents.

The developer claims that the FIVE system is most effective at removing the following compounds:

- Compounds that exhibit significant volatility at ambient temperatures in soils
- Compounds exhibiting vapor pressures more than 0.5 mm of mercury
- Compounds that have Henry's law constants greater than 0.01

The FIVE system has been used in full-scale cleanups. IT Corporation currently owns the rights to the technology.

According to the developer, the FIVE system offers the following advantages:

- Removes VOCs in a cost-effective manner.
- Causes minimal site disturbance.
- Uses standard equipment.
- Treats large volumes of soil.

The technology cannot be used to treat nonvolatile compounds, lubrication oils, and heavy end products from petroleum processing except when the technology is configured for bioventing with air injection and nutrient addition.

Technology Cost

The cost for using the FIVE system technology for remediation ranges from \$30 to \$60/yd^3 of contaminated soil. Unit costs can range as low as \$18/lb of volatile compounds removed (D13960Q, p. 3).

The factors that affect the cost for using the technology include:

- Initial contaminant concentration
- Target contaminant concentration
- Depth of contamination
- Depth to groundwater
- Waste quantity
- Residual waste characteristics
- Site preparation
- Waste handling/preprocessing
- Amount of debris
- Utility/fuel rates
- Labor rates (D13960Q, p. 8)

At the Sand Creek Superfund site, project costs were \$2.14 million. This value does not include the cost for demobilization activities. It was determined that \$81,231 of the total cost of the project was spent on mobilization and other pretreatment activities. Activities relating to treatment accounted for \$2,058,564 of the total project cost. This corresponds to a treatment cost of \$39 to \$65/yd^3 of soil treated and \$11.70/lb of VOCs removed (D22777U, p. 23).

At the Sacramento Army Depot site, project costs were \$865,873. It was determined that \$195,362 of the total cost of the project was spent on mobilization and other pretreatment activities. Activities relating to treatment accounted for \$670,511 of the total project cost. This corresponds to a treatment cost of \$2.70/yd^3 of soil treated and \$4858/lb of VOCs removed (D22778V. p. 27).

The technology was applied at the Camp Lejeune Military Reservation, Site 82, Area A in Onslow County, North Carolina. The system was installed in 1995. From April 1995 through December 1995, approximately 17,500 yd^3 of soil were treated in this full-scale application. The total cost of the remediation was \$469,940. This total includes \$222,455 in capital costs and \$247,485 in operation and maintenance (O & M) costs (D196558, pp. 1–3).

Information Sources

D13960Q, U.S. DOE, 1996
D22777U, U.S. EPA, 1995
D22778V, U.S. EPA, 1995
D196558, U.S. EPA, 1998

T0440

IT Corporation

Groundwater Bioremediation

Abstract

IT Corporation's (IT's) bioremediation technology treats contaminated groundwater and saturated soils. The commercially available technology utilizes extraction and injection wells to deliver nutrients and oxygen to contaminated areas to stimulate indigenous bacteria activity. Organic matter is oxidized by bacteria into innocuous end products including carbon dioxide and water.

According to the vendor, this technology is limited to treating aqueous-phase contaminants and is less cost-effective than other technologies in treating free-phase product. In treating aqueous-phase contaminants, the technology is limited by the subsurface transport of nutrients and oxygen due to soil mineral content and hydraulic conductivity. A high soil sorptive capacity may make contaminants unavailable for microbial degradation.

Technology Cost

The vendor estimates the cost of treatment using the bioremediation technology to be between \$0.05 and \$0.10/gal of waste. Factors having the greatest effect on unit price include quantity of waste, depth to groundwater, and target and initial contaminant concentration. This price may not include all indirect costs associated with the treatment (D10308S, p. 13).

The vendor claims that this technology costs 60% less than pump-and-treat technologies (D10308S, p. 2).

Information Source

D10308S, VISITT 4.0, 1995

T0441

International Technology (IT) Corporation

Hybrid Thermal Treatment System (HTTS)

Abstract

The Hybrid Thermal Treatment System (HTTS) is a patented, ex situ, commercially available technology for the treatment of liquids, solids, and sludges contaminated with hazardous organic compounds, including explosives. The vendor states that the technology has been used to treat over a million tons of hazardous waste at multiple project locations in the United States and is currently commercially available.

HTTS is a completely modular, transportable incineration system. A rotary kiln heats contaminants and vaporizes hazardous organic components. The gaseous waste is then subjected to intense heat in the secondary combustion chamber. Gases are then cleaned by a wet quench and scrubber before being discharged. The ash produced by the kiln is nonhazardous and can be back-filled on site.

Inorganic contaminants cannot be destroyed by incineration. Residual ash with elevated levels of heavy metals must be stabilized prior to disposal.

Technology Cost

In 1995, IT Corporation published an economic estimate of an HTTS using oxygen rather than air for combustion. Results indicate that the modification could reduce the time required to remediate the site. The vendor stated that for every month's reduction in the length of the project, $500,000 would be saved from project costs. Therefore the cost of steady-state operation of an HTTS is estimated to be $500,000 per month (D106172, p. 61).

At the Sikes Disposal Pits Superfund site in Crosby, Texas, an HTTS unit was used to treat hazardous organic compounds including phenolic compounds, xylene, benzene, polynuclear aromatic hydrocarbons (PAHs), toluene, creosote, dichloroethane (DCA), vinyl chloride, and naphthalene (D184581, p. 216). The estimated treatment cost was $115 million including approximately $20 million in capital costs and $95 million in operation and maintenance costs. The estimated total cost for thermal treatment was $81 million. A total of 496,000 tons of soil and debris were incinerated. This corresponds to a total unit cost for incineration of $230 per ton and a unit cost of $160 per ton for thermal treatment (D184581, p. 227).

At the MOTCO Superfund site in Texas City, Texas, soil and groundwater contamination resulting from chemical disposal activities included styrene, volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), benzene, vinyl chloride, 1,1,2-trichloroethane (TCA), lead, cadmium, mercury, and chromium. Two HTTS systems were used at this site. The cost of on-site incineration was approximately $76 million including $20 million in capital costs and $56 million in operating costs (D18464Z, p. 129). A total of 23,021 tons of material, including soil, sludge, organic liquid, and aqueous waste, were incinerated. This corresponds to a total unit cost for incineration of $3300 per ton (D18464Z, p. 138).

At Times Beach, Missouri, a pharmaceutical and chemical company produced wastes that contained 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) from the production of hexachlorophene. The operational costs for a single HTTS unit was $110,000,000. A total of 265,000 tons of soil and debris were incinerated. This corresponds to a total unit cost for incineration of about $800 per ton (D184570, p. 243).

Information Sources

D106172, Acharya and Schafer, 1995
D18464Z, U.S. EPA, 1998
D184581, U.S. EPA, 1998
D184570, U.S. EPA, 1998

T0442

International Technology Corporation

In Situ Air Sparging

Abstract

International Technology (IT) Corporation applies in situ air sparging for the remediation of contaminated groundwater. This technique involves blowing air into groundwater to help volatilize

organic constituents. Most applications of this technique use soil vapor extraction with the air sparging to remove the soil vapors from the groundwater. In situ air sparging is sometimes used without soil vapor extraction in a biosparging mode. In biosparging, oxygen is introduced to encourage bioremediation. This technology can be combined with IT's ozonation technology by pumping an ozone–oxygen solution into the well instead of air (D19400N, p. 5). In situ air sparging is suitable for removing volatile organic compounds (VOCs) from groundwater. Typical VOCs treated include volatile components of petroleum hydrocarbon such as benzene and volatile solvents such as trichloroethylene.

The technology has been used in full-scale field applications and is commercially available. IT has several pilot systems available for on-site treatability studies.

Technology Cost

The vendor estimates that the price range for air sparging is between $15,000 and $50,000 per half to one acre. Factors that influence the final price per acre are soil characteristics, depth to groundwater, depth of contamination, initial contaminant concentration, target contaminant concentration, and the characteristics of the residual waste (D10309T, p. 22).

At a former manufactured gas facility in Long Beach, California, International Technology Corporation's in situ air sparging apparatus was combined with its ozonation technology. Construction and operation costs for the project from 1998 to 2000 are estimated to be $1,000,000 (D19400N, pp. 5, 6).

Information Sources

D10309T, VISITT 4.0, 1995
D19400N, Cambridge and Jensen, 1999

T0443

IT Corporation

In Situ Geochemical Fixation

Abstract

Fluor Daniel GTI, Inc. (now part of the IT Corporation), has developed in situ geochemical fixation technology to immobilize metallic contaminants in soil, sediment, sludge, and groundwater. The technology uses a site- and contaminant-specific combination of reagents to convert ionic contaminants to less soluble forms. In situ geochemical fixation has been used to remediate sites contaminated with chromium, uranium, molybdenum, and copper.

The vendor claims the following benefits of in situ geochemical fixation:

- Remediates metals up to 10 times faster than pump-and-treat systems.
- Reduces cleanup costs compared to pump-and-treat systems.
- Allows existing pump-and-treat systems to be used to operate the technology.
- Treats metals in place, minimizing site disruptions to support continued site use.

For in situ geochemical fixation, site characterization data and reagent concentrations are more exacting than those required for a pump-and-treat approach. Therefore, the use of the system requires a detailed analysis of site conditions and careful system engineering. Site and contaminant characteristics have a large impact on treatment cost and effectiveness.

Technology Cost
In 1997, it was reported that the vendor was using in situ geochemical fixation to remediate a Midwestern wood treatment site contaminated with chromium. The cleanup is expected to last for 2 years and cost approximately $600,000. The vendor states that treating the site by conventional pump-and-treat technology would have taken more than a decade to complete and would have cost far more (D16925Z, p. 1).

Treatment using in situ geochemical fixation will be highly contaminant and site specific. Site factors that influence processing include clay content, pH, total organic carbon content, iron and manganese oxide content, and cation exchange capacity (D16925Z, p. 1).

Information Source

D16925Z, EnviroNet, 1997, web page

T0444

IT Corporation

Oxygen Microbubble In Situ Bioremediation

Abstract
This technology uses oxygen microbubbles for in situ bioremediation of contaminated groundwater in the saturated zone. The microbubbles provide an effective medium for delivering oxygen, nutrients, and microorganisms to the treatment zone. The bubbles eventually coalesce and continually saturate the groundwater with oxygen. One of the advantages of this technology, when compared with air sparging, is that the microbubbles can remain intact for long periods of time so oxygen does not need to be continually pumped and the system can be operated on a pulsed cycle instead.

The technology has successfully treated groundwater contaminated with a number of organic compounds including petroleum hydrocarbons, organic solvents, creosote, and pentachlorophenol.

Technology Cost
According to the vendor, this technology may provide the greatest amount of oxygen for the longest time at the lowest cost. Exact costs are not available yet, but the cost is expected to be very competitive with more frequently used oxygen distribution methods such as groundwater saturation and air sparging. Cost depends in part of the type and amount of surfactant used (D111900, p. 80).

Information Source

D111900, Ground Water Monitor, 1995

T0445

IT Corporation

Ozonation

Abstract
IT Corporation offers techniques that use ozone to oxidize contaminants in the subsurface or in above-ground treatment cells. Ozonation can be used as a primary treatment step, as a pretreatment step prior to bioremediation, or as a polishing step after other technologies. Ozonation has been tested in the laboratory, in pilot-scale demonstrations, and in full-scale applications. Patent

applications have been filed for the use of ozone to treat soil and groundwater. The ozonation technology offered by IT Corporation is commercially available.

According to the developer, ozonation has the following advantages:

- Unlike some liquid oxidants, ozone readily disperses through soil.
- Ozone easily dissolves in groundwater.
- The ozonation process is rapid.
- Ozone typically causes minimal ion exchange and metals precipitation.
- The process breaks down some contaminants into simpler compounds that can be further degraded by microorganisms.

Ozonation has the following potential limitations:

- Factors such as pH and moisture can affect the process.
- Some metals can limit the generation of hydroxyl radicals.
- The process may not be effective in low-permeability soils or in soils with high natural organic content.
- The ozone molecule can react with incompatible materials, such as treatment system components.
- Ozone is regulated by the Occupational Safety and Health Administration (OSHA), and ambient discharges of the molecule must be controlled.
- Saturated hydrocarbons may not be efficiently treated by ozone.
- The microbial viability of soil can be virtually eliminated by the constant addition of ozone.

Technology Cost

The vendor claims that using ozone to treat a 1-acre site contaminated with 1 part per million (ppm) trichloroethene (TCE) would cost approximately $269,000. This estimate assumes "20 ft of thickness." Treating the same site using alternative oxidants would be less expensive. Hydrogen peroxide would cost about $201,000, sodium manganate would cost about $187,000, and potassium manganate would cost about $136,000 (D203816, p. 6).

Small portable corona discharge ozone generators (with capacities of less than 10 lb per day) typically cost $10,000 to $20,000. Larger portable units can cost more than $75,000. Laboratory treatability studies generally cost $5000 to $10,000 (D15853W).

At a former manufactured gas plant in Long Beach, California, IT Corporation ozonation and in situ air sparging were combined to treat contaminants such as benzene, naphthalene, and benzo(*a*)pyrene in groundwater and soil. Construction and operation costs from 1998 to 2000 were estimated to be $1,000,000 (D19400N, p. 6).

Information Sources

D15853W, Nelson and Brown, 1994

D16996E, Cheremisinoff, 1994

D19400N, Cambridge and Jensen, 1999

D203816, U.S. EPA, 1999

T0446

IT Corporation

Photolytic and Biological Soil Detoxification

Abstract

IT Corporation (IT) developed a two-stage photolytic and biological soil detoxification process to treat soils contaminated with polychlorinated biphenyls (PCBs) and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD). The photolysis/biodegradation process has been evaluated under the U.S.

Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) Emerging Technology Program.

The first step in the process is to break organic contaminants into biodegradable compounds using ultraviolet (UV) radiation. Biological degradation is then used to further destroy organic contaminants and detoxify the soil. The biodegradation is enhanced by the addition of microorganisms and nutrients to the UV-treated soil.

The technology was designed to be applied in situ for the treatment of contaminants in shallow soil. However, it can be applied as an ex situ treatment, for excavated soils, in specially constructed shallow treatment basins.

Extensive tests determined that the technology is unable to significantly reduce contamination concentrations in soils. As a result, the technology is no longer available through IT.

Technology Cost
No available information

T0447

IT Corporation

Slurry-Phase Bioremediation — Full Scale

Abstract
IT Corporation has developed bioremediation techniques that have been used to remediate soils, sludges, and groundwater contaminated with explosives, petroleum hydrocarbons, petrochemicals, solvents, pesticides, wood preservatives, and other organic chemicals. IT's slurry-phase bioremediation is a commercially available ex situ technology for the treatment of soil and sludge containing biologically degradable contaminants. The process uses a bioreactor to treat waste in the form of a slurry containing contaminated material, water, nutrients, and microorganisms.

Slurry-phase bioremediation is typically more rapid than other types of bioremediation since contaminants are solubilized in a slurry, making them more readily available to microorganisms. The process is enhanced by providing the microorganisms with appropriate nutrients and environmental conditions to optimize the reaction rate. Bioremediation can degrade organic compounds to carbon dioxide, water, and other products leaving little or no residual waste from the treatment process.

Bioremediation is not effective in the removal of metals, cyanides, and some chlorinated compounds. High levels of some contaminants may inhibit biological activity in the treatment system. A treatability study is typically performed prior to initiation of a full-scale treatment system to determine the applicability of slurry-phase bioremediation. If ambient temperatures are low, heating of the bioreactor may be required.

Technology Cost
The vendor specified three variables that have a significant impact on the cost of remediation using bioslurries: the slurry-phase reactor solids concentration, residence time in the reactors, and the percentage of material removed in the slurry preparation/soil washing process. According to the vendor, increasing the solids concentration in the reactors increases the amount of soil treated per batch. This results in a decrease both in total number of batches treated and the cost per ton of treatment. In addition, longer batch residence times reduce the system throughput and, therefore, increase the cost of treatment. The higher the percentage of material that is removed

TABLE 1 Approximate Costs of On-Site Treatment Technologies (1994)

Technology	Typical Cost per Ton
Incineration	\$400–\$1,000
Chemical oxidation	\$200–\$500
Stabilization	\$120–\$520
Solvent extraction	\$100–\$500
Slurry-phase bioremediation	\$200–\$500

Source: Adapted from D12940I, p. 362.

TABLE 2 Cost Analysis for Slurry-Phase Biological Treatment of 10,000 yd^3 (1994)

Task	Labor	Equipment	Materials & Supplies	Utilities	Analytical	Task Subtotal
Design and procurement	\$160,000	\$0	\$22,000	\$0	\$0	\$182,000
Site preparation and equipment setup	\$118,000	\$16,000	\$260,000	\$25,000	\$0	\$419,000
Soil screening	\$22,000	\$53,000	\$2,000	\$500	\$0	\$77,500
Slurry preparation	\$155,000	\$75,000	\$15,000	\$8,000	\$0	\$253,000
Slurry biological treatment	\$95,000	\$165,000	\$115,000	\$200,000	\$72,000	\$647,000
Slurry dewatering	\$160,000	\$112,000	\$11,000	\$3,500	\$0	\$286,000
Decontamination and demobilization	\$75,000	\$9,000	\$63,000	\$0	\$0	\$147,000
Project administration	\$185,000	\$45,000	\$37,000	\$3,000	\$0	\$270,000
Category subtotal	\$970,000	\$475,000	\$525,000	\$240,000	\$72,000	\$2,282,000

Source: From D12940I, p. 356.

by the slurry preparation/soil washing process, the lower the cost for the bioreactors since less material will remain biologically treated (D19496B, p. 22).

According to the vendor, costs for slurry-phase bioremediation range from \$200 to \$230/yd^3 in 1994. A cost comparison of various on-site treatment technologies is presented in Table 1 (D12940I, pp. 353, 362).

Estimated costs for a slurry-phase treatment system are presented in Table 2. The figures are based on the following assumptions: the total volume of material is 10,000 yd^3, with 5000 yd^3 removed by soil preparation; slurry in the reactors is a 25% solids concentration; the reactors are operated in batch mode, and require 30 to 35 days for each batch; the system is operated for 7 days a week for the duration of the project (D12940I, p. 356).

Approximately \$2,900,000 were expended on the bioslurry application at the Southeastern Wood Preserving Superfund Site. Costs directly attributed to treatment included costs for mobilization and set up (design engineering) of \$100,000; and startup, testing, and permit costs (treatability and pilot-scale testing) of approximately \$200,000. In addition, operation costs were approximately \$2,100,000 and included soil screening and slurry preparation, slurry treatment, slurry dewatering, and project administration and support. The cost for treatment activities corresponds to \$170/ton (\$230/yd^3) of soil and sludge treated (14,140 tons, or 10,500 yd^3). After treatment costs totaled \$500,000 and included site restoration and closure (D19496B, p. 21).

Information Sources

D12940I, Woodhull and Jerger, Remediation/Summer 1994
D19496B, U.S. EPA, undated

T0448

IT Corporation

Slurry-Phase Bioremediation — Pilot Scale

Abstract
The IT Corporation (IT) slurry-phase bioremediation technology is applicable to biodegradable compounds such as solvents, petroleum products, certain chemical manufacturing wastes, and biological sludges.

The technology can treat organic contaminants such as pesticides, fuels, creosote, and pentachlorophenol. The technology has treated coal tars, refinery wastes, hydrocarbons, and wood preserving wastes in full-scale applications.

The IT process can treat slurries containing up to 40% solids and contaminants in the 1000s parts per million range.

The characteristics of the contaminated materials that make it appropriate for bioslurry treatment include:

- 0.025 to 25% organics by weight
- 10 to 40% solids by weight
- Less than $\frac{1}{4}$-inch material size

Technology Cost
The estimated price range for using the IT slurry-phase bioremediation technology is $175 to $250/yd^3 of waste treated. Based on the treatment of 800 lb of soil, sludge, or sediment in a pilot-scale treatability study, the IT slurry-phase bioremediation technology cost is estimated to be $175/yd^3 (D10307R, p. 10).

Information Source

D10307R, VISITT 4.0, 1995

T0449

IT Corporation

Thermal Desorption

Abstract
IT Corporation's thermal desorption system is a commercially available, ex situ technology for the treatment of soils and sludges contaminated with organics. The process drives volatile and semivolatile organic compounds (VOCs and SVOCs) from the soil by heating the soil to temperatures greater than the boiling point temperature of the contaminants. Volatized vapors are oxidized in a secondary combustion chamber or collected for physical/chemical treatment.

IT thermal desorption has been used for several years to demonstrate removal of chlorinated phenols, pesticides, polycyclic aromatic hydrocarbons (PAHs), dioxins, polychlorinated biphenyls (PCBs), solvents and mercury from soils and sludges.

Thermal desorption treatment is generally considered to be an alternative to incineration. Thermal desorption operates at much lower temperatures than incineration and keeps the heating systems independent of the wastes, which minimizes off-gas production. The technology can be used as a waste minimization process, isolating and concentrating waste constituents, or as a product recovery process. Thermal desorption can also be used to separate contaminants in mixed waste streams by removing volatile constituents.

The process is limited to organic compounds and selected metals (those with significant vapor pressure at 650°C such as mercury). Soil or sludge with other heavy-metal contaminants will require additional treatment. Solids must be crushed to a size less than 2 inches to be processed in the system.

While PCBs can be readily removed from soil, chlorinated furans can be produced in significant quantities if the process conditions are not controlled. Thermal desorption can lead to solids without furan contamination, but only if the operator understands the phenomena and controls the processing conditions.

Technology Cost

In 1991 the vendor estimated the cost of thermal desorption technology to be approximately $80 per ton of soil treated, based on a system that treats soil with 20% moisture content at a rate of 10 tons per hour. This cost includes $20 per ton for depreciation and $60 per ton for labor, utilities, fuel, materials and supplies, and administrative costs (D12872N, p. 44).

Information Source

D12872N, Fox et al., February 1991

T0450

IT Corporation

Thermal Destruction Unit

Abstract

The IT Corporation thermal destruction unit is a mobile unit that uses infrared incineration technology. The main objective of this process is to transform the feedstock into another form (an ash acceptable for delisting) while assuring safe discharge of exhaust gas products to the environment. The unit is capable of on-site remediation of wastes and soils contaminated with polychlorinated biphenyls (PCBs) and other organics. This technology is based on a conveyor belt furnace process.

Advantages of this technology include the precise solid waste retention time and reduction of gas flows that are obtained by indirectly heating the soil with radiant tubes. This technology is commercially available.

Operational problems with the freshwater vapor quenching system may cause high particulate emissions.

Technology Cost

Hopper-to-hopper treatment costs (including equipment mobilization and demobilization) range from $250 to $350 per ton ($276 to $386 per metric ton) (1991 dollars) of waste treated for projects with waste quantities in excess of 10,000 tons (9100 metric tons) (D12683K, p. 218).

Information Source

D12683K, Hay and McCartney, 1991

T0451

J.M. Huber Corporation

Advanced Electric Reactor

Abstract

The advanced electric reactor (AER) is an ex situ thermal treatment technology. The treatment process uses a high-temperature fluid-wall reactor that heats organic compounds to temperatures in the range of 2200°C. The reactants are isolated from the reactor core walls by a gaseous blanket of nitrogen flowing radially inward through the porous core walls. Carbon electrodes are heated and, in turn, heat the reactor core so that heat transfer is accomplished by radiative coupling from the core to the feed materials. The only feed streams to the reactor are the solid waste containing polychlorinated biphenyls (PCBs) and the blanket gas (nitrogen). PCBs are destroyed by pyrolysis (the thermal rupture of the chemical bonds of a molecule) rather than oxidation. According to the vendor, typical products produced by incineration such as carbon monoxide, carbon dioxide, and oxides of nitrogen are not formed in significant concentrations (D13468J, p. 46).

The AER was developed by J.M. Huber Corporation. The process is patented and all patents are owned by the vendor. In 1984, the process was fully permitted under the Toxic Substance Control Act in Environmental Protection Agency Region VI for the destruction of PCBs (D13468J, p. 46). RIMS was unable to contact the vendor, thus the technology's current commercial status is unknown.

Technology Cost

The following cost information is in 1984 dollars and was supplied by the vendor. It has not been independently verified.

The cost of using AER to treat a very large volume of soil is estimated at \$412/ton (\$763/m^3). This estimate is a budgetary cost figure and does not include the costs of dredging, transporting soil to the AER site or facilities for storage of dredged soil. It also does not provide for cost of landfilling or other disposal of the treated sediment.

The capital cost for construction and initial testing of a single 25,000 ton a year transportable AER is approximately \$4 million, not including permits and trial burns. With six units, it would require approximately 3.5 years to treat 382,000 m^3 of sediment. Including dredging and transport for treatment and redeposition or treated sediments the overall cost estimate would equal \$829 to \$942/m^3 (D13468J, p. 53).

Information Source

D13468J, Carpenter, 1986

T0452

Joule-Heated Vitrification — General

Abstract

Vitrification, the process of converting materials into a glass or glasslike substance, is gaining popularity as a method of treating various hazardous wastes. Vitrification allows for the treatment of many different kinds of waste and produces a durable, leach-resistant final waste product. During the process of thermal vitrification, organic contaminants are typically destroyed, and inorganic materials are melted.

Many vitrification technologies operate on the principle of electrical resistance heating, also called Joule heating. In Joule heating, an electric current passes through the treatment material, and the resistance of the current gives off heat, allowing the formation of glass. Vitrification technologies are commercially available for many remediation applications both in the United States and internationally.

Vitrification may proceed as either an in situ or ex situ technology. The advantage of in situ methods is that handling of the wastes is minimized. The advantage of an ex situ technique is the ability to control processing, and to control the final waste form created. In some instances, the materials created during ex situ processing may have economic value, depending on the method used to melt the waste, and the properties of the contaminated material.

Vitrification has four major advantages over other methods of waste management. The primary advantage is the durable final waste form glass produced. In most cases, the glass performs exceptionally well in leach tests. Because of the chemical and physical durability of the produced glass, it has been considered for recycling as aggregate or other products. The second major advantage of vitrification is the flexibility of the waste glass in incorporating a wide variety of feed materials, without markedly diminishing the quality of the glass. The third advantage of vitrification is the ability to process both organic and inorganic wastes. Lastly, vitrification may result in a significant volume reduction of the treated waste.

Vitrification's main limitation is that it is extremely energy intensive, and thus may be more expensive than other remedial technologies. A second major limitation is the potential for some contaminants (organic and inorganic) to volatilize during treatment.

Technology Cost

Most of the cost data for vitrification technologies are estimates based on pilot-scale operations. Such data are suspect because they are based more on extrapolation than on experience. Such estimates are difficult to compare because the assumptions on which they are based may vary widely (D18248T, p. 55).

Many site specific characteristics have an impact on vitrification technologies. One critical aspect of any thermal technology is the water content of the waste. Water dilutes feed material, requires energy to drive off, and physically limits the feed rate of waste. Feed preparation is another variable, which differs with the technology and with site-specific characteristics. Some technologies can accept complete barrels of waste at a time, while others require pretreatment and size reduction. Many estimates do not take into account site preparation and waste disposal costs. Only complete treatment life-cycle assessments can provide reliable comparison data, and such studies are, by definition, highly site and waste specific (D18248T, p. 55).

Various sources estimate vitrification costs as ranging from under \$100/ton to over \$1000/ton for units treating hazardous waste. These estimates are assumed to be for treatment only, not including pretreatment and disposal costs. The extreme variability of the costs may be attributable to differences in feed type and water content of the waste (D18248T, p. 55).

Some ex situ Joule-heated melters that are summarized in the RIMS database are the Battelle Pacific Northwest Laboratory Terra-Vit vitrification technology (T0088), The Stir-Melter, Inc., Stir-Melter (T0752), the Westinghouse Savannah River Company transportable vitrification system (T0887), the GTS Duratek DuraMelter (T0359), the EnVitCo, Inc., high-temperature Joule-heated vitrification system (T0808), and the Ferro Corporation's waste vitrification through electronic melting technology (T0306). Cost estimate information has been provided for the Terra-Vit vitrification technology, the Stir-Melter technology, the DuraMelter, and the EnVitCo systems. A cost estimate for the EnVitco high-temperature Joule-heated vitrification system is included below as a representative cost estimate for ex situ Joule-heated melters.

Ex Situ Joule-Heated Vitrification, Envitco, Inc In undated vendor literature supplied in 1997, Davis estimates that treating a hazardous waste incinerator waste stream would cost from \$131.30 to \$266.90 per ton of dry waste treated. This cost estimate is summarized in Table 1. Costs vary depending on feed rate and the degree of waste reduction achieved during treatment. The estimate

TABLE 1 Vendor-Supplied Cost Estimates in Dollars/Ton for Envitco Treatment of Incinerator Ash

Dry waste/glass ratio	0.70	0.70	1.05	1.05
Tons/day glass produced	25	100	16.7	66.8
Tons/day dry waste processed	17.5	70	17.5	70
Premelting costs				
Raw materials	33.40	33.40	0	0
Pretreatment				
Capital	6.30	2.10	9.00	3.00
Utilities	5.60	4.40	7.70	6.60
Manpower	5.70	2.90	8.60	4.30
Batch house				
Capital	11.00	3.60	14.70	4.60
Utilities	1.20	0.60	1.50	0.70
Manpower	5.70	2.90	8.60	3.20
Melting costs				
Capital	13.60	12.20	20.30	13.60
Utilities	62.10	61.70	65.30	64.70
Manpower	22.90	17.10	34.20	17.10
Forming costs				
Capital	0.90	0.90	1.40	0.90
Utilities	0.30	0.20	0.40	0.30
Manpower	1.90	1.40	2.90	1.60
Rebuild accrual costs	6.90	6.90	6.90	6.90
Maintenance supply costs	4.00	4.00	4.00	4.00
Maintenance labor costs	5.70	4.30	8.60	6.40
Total cost/ton of glass produced	187.30	158.50	194.00	137.90
Total cost/ton of dry waste treated	266.90	225.90	184.70	131.30

Source: Adapted from D14867Y.

was performed for two types of glass compositions, which are described in Table 2. The vendor notes that the cost of vitrification and alternate options for any waste is highly site specific and include the individual factors determining total costs to provide a basis for comparison (D14867Y, pp. 6–10).

It is assumed in estimates 1 and 3 that a single Envitco melter would be used. For estimates 2 and 4, a bank of four melters operating in tandem was used. For estimates 2 and 4, it was assumed that at any one time three of the four melters would be operational. It is noted that the use of injected air or oxygen instead of sodium nitrate would lower treatment costs (D14867Y, p. 8).

The vendor notes that the energy required for melting is the largest component of cost, and that these costs would be highly site dependent. Abatement costs for the off-gas were estimated at $0 because the estimate was based on a waste stream that had already been processed by an incinerator. Forming of the wastes is accomplished by directing the molten glass stream into water, cracking the glass. A continuous screw mechanism takes the produced glass out of the water for further draining. The produced glass may have economic applications as a binder material, filler, or as a component of glasphalt. In the estimate of rebuild accrual and maintenance is the cost of replacing the inner lining of refractories in the melter and other expected maintenance (D14867Y, pp. 8–10).

In situ Joule-heated vitrification systems discussed in the RIMS database include the Geosafe Corporation's in situ vitrification (ISV) system (T0344), and the Bio-Electrics, Inc., Electrofrac

TABLE 2 Composition of Glass Types Used for Economic Analysis

Component	Optimized Glass Form with Additives	Nonadditive Glass Formulation
Bottom ash	60%	90%
Fly ash	6%	10%
Sand	25%	0%
Sodium nitrate	7%	0%
Soda ash	3%	0%
Waste/glass ratio[a]		
Dry	0.7	1.05
Wet	1.0	1.3

Source: Adapted from D14867Y.
[a]The ratio of the weight of the untreated waste to that of the glass product.

detoxification system (T0095). In 1995, the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration program evaluated ISV technology. The information included in the cost information for the ISV system is included as a representative cost estimate for in situ Joule-heated melters.

In Situ Joule-Heated Vitrification—Geosafe Corporation Based on data collected during the SITE demonstration program evaluation in 1995, a cost estimate was prepared for ISV treatment of soil. The cost for treatment when the soil is staged into nine cells is approximately \$1300/yd^3 for 5-ft-deep cells, \$770/yd^3 for 15-ft cells, and \$660/yd^3 for 20-ft-deep cells. These estimates are for the contaminated soil only. Cost estimates do not include vendor profit (D123320, p. 41). For sites backfilled, total volume of material treated will be higher than the amount of contaminated soil treated (D123320, p. 7). These cost estimates are summarized in Table 3.

In 1994, average costs for treatability studies were estimated by the vendor to be \$25,000, excluding analytical fees, or \$30,000, analytical fees included. Equipment fees and mobilization costs were estimated at \$200,000 to \$300,000 combined (D10857G, p. 4–36). Also in 1994, costs for ISV processing were estimated to average \$350 to \$450/ton for hazardous wastes and \$400 to \$550/ton for radioactive wastes (D13589R, p. 2).

Operating costs are dependent on site conditions. Factors that impact cost include the amount of site preparation required, properties of the media to be treated (density, water content, etc.), volume of material to be processed, depth of processing, unit price of electricity, and season of the year. Costs can vary by \$55 to \$77/metric ton between treating dry soil and treating fully saturated soil. In such cases, predrying the soil may become cost effective (D136016, pp. 853–854).

Information Sources

D10857G, U.S. Department of Defense, 1994

D123320, U.S. EPA, 1995

D13589R, Ames Laboratory, 1994

D136016, Smith, 1994

D14867Y, Davis, vendor literature, date unknown

D18248T, Sigmon and Skorska, 1998

TABLE 3 Summary of Economic Analysis Estimates for In Situ Joule-Heated Vitrification[a]

Amount of Material Treated	Case 1: 970 yd^3	Case 2: 3200 yd^3	Case 3: 4400 yd^3
Cost category	$/yard^3	$/yard^3	$/yard^3
Site preparation	51	18	13
Permitting	27	9	7
Equipment	190	98	83
Startup and fixed	260	130	110
Labor	250	150	130
Consumables and supplies	80	61	52
Utilities	180	170	160
Effluent treatment	0	0	0
Residuals and wastes, shipping and handling	34	26	23
Analytical services	52	19	14
Facility modifications and maintenance	170	86	59
Demobilization	37	13	9
Total cost/ton	1,300	770	660

Source: Adapted from D123320, p. 34.
[a]Estimates are based on a wet soil density of 1.8 tons/yd^3 based on SITE demonstration results. Costs based on contaminated soil treated. All costs are rounded to two significant figures, based on the sum of the individual costs before rounding.

T0453

EG & G Rocky Flats

Supercritical Carbon Dioxide Extraction

Abstract
Supercritical carbon dioxide extraction (SCDE) is an ex situ process for the treatment of low-level solid mixed and land disposal restricted (LDR) wastes. SCDE can extract hazardous solvents from waste substrates to produce land-disposable, low-level wastes. The process employs the supercritical fluid carbon dioxide as a solvent. This fluid is noncombustible, nontoxic, and environmentally safe. In its supercritical state, carbon dioxide can dissolve organic contaminants allowing the fluid to quickly penetrate and facilitate transfer out of a contaminated matrix.

Large quantities of low-level solid mixed wastes such as rags, coveralls, paper, plastics, and surgeon's gloves contaminated with radionuclides, oils, greases, and hazardous solvents have been generated at nuclear weapons manufacturing sites across the country. As long as the hazardous oils, greases, or solvents are present, these wastes are considered LDR and cannot be disposed of at any site in the country. SCDE is an organic contaminant removal technology that can be used to render these wastes into acceptable low-level waste forms.

In bench-scale testing, SCDE has demonstrated the ability to extract volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) including polychlorinated biphenyls (PCBs) from various substrates.

Motor oils and machine coolants containing paraffin and long-chain polymers tend to be difficult to extract by SCDE.

Technology Cost
No available information.

T0454

KAL CON Environmental Services

Thermal Desorption

Abstract
The KAL CON Environmental Services (a division of Kalkaska Construction Services, Inc.) thermal desorption process is an ex situ treatment technology that removes hydrocarbon contamination from soil. This process has been used to treat soils contaminated with gasoline, jet fuel, diesel fuel, kerosene, crude oil, and crude condensate.

This technology is currently commercially available.

According to the vendor, this technology has the following advantages:

- The facility provides for the remediation and recycling of the soils, thereby removing the threat of further contamination of the groundwater and air.
- Destruction of the petroleum contamination eliminates future liability and potential environmental problems that may occur if the contaminants were not destroyed.

KAL CON's thermal units are applicable to treatment of hydrocarbon-contaminated soils but may not be used to remediate soils contaminated with polychlorinated biphenyls (PCBs), radioactive isotopes, or dioxins. Pesticides and herbicides can be treated by low-temperature thermal desorption, but special permitting is required and may be difficult to obtain.

Technology Cost
The estimated cost for this technology is \$35 to \$60 (1995 dollars) per ton of waste treated. This estimate does not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals.

Factors that have a significant effect on the unit price of this technology include the following:

- Quantity of waste
- Initial contaminant concentration
- Amount of debris with waste
- Site preparation
- Waste handling/preprocessing

The moisture content in the soil will affect how many tons per hour can be remediated. The higher the moisture content, the longer it takes for remediation (D102965, p. 23).

Information Source

D102965, VISITT Version 4.0, 1995

T0455

Kansas State University

Vibrorecovery

Abstract
Dr. Lakshmi Reddi of the Department of Civil Engineering at Kansas State University has investigated the use of localized vibrations for controlled mobilization and collection of light

non-aqueous-phase liquids (LNAPLs) from ganglia (or “blobs”) near the water table, a technique he calls vibrorecovery. Residual ganglia of LNAPLs can be left after pumping of free product and may occupy 20 to 60% of the pore space. Bench-scale testing of vibrorecovery indicates that up to 85% of the ganglia may be removed by the technology. Thus far, the vibrorecovery technique has only been tested at the bench-scale and is not commercially available.

All information is from the developer and has not been independently verified.

Technology Cost

The cost of vibratory mobilization of ganglia would depend on the soil and NAPL properties, the areal and vertical extent of contamination, the initial state of the soil, the required level of remediation (i.e., ganglia lengths), and the required number of vibroflot penetrations. A 1969 estimate for densifying sands by vibroflotation to a relative density of 0.70 to 0.75 was \$2.80 to \$3.90 but is probably not directly applicable to this remediation technology (D15491Q, p. 43).

Information Source

D15491Q, Reddi, 1994

T0456

Keller Environmental, Inc.

BioInjection

Abstract

BioInjection™ is an in situ, commercially available bioremediation technology for the treatment of soils contaminated with light- to medium-weight petroleum compounds to a depth of 40 ft (12 m). The technology injects a slurry of water, oxygen, nutrients, and degrading microbes into the subsurface. Using multiple injections in an overlapping grid pattern increases permeability and transmissivity of the slurry and assures its distribution to all contaminated areas.

The time required for remediation with BioInjection is shorter than many traditional methods because the treatment is brought to the contaminants, rather than moving the contaminants through the soil, i.e., as in soil vapor extraction. Because the slurry physically permeates the contaminated area, the technology is effective on all types of inorganic and organic soils, including clays. The technology cannot treat gravel or cobbles.

BioInjection produces no air or wastewater emissions, requires no landfilling or odor control, and can be performed in or around an operating facility.

Technology Cost

The cost for BioInjection treatment was estimated in 1995 to be \$20 to \$50/yd^3 (\$26 to \$65/m^3) (D12584I, p. 533).

Geographic location, site conditions, and the slurry contents (particularly the oxygen source material) all affect the overall cost. In 1993, the cost for injection services ranged from \$8 to \$25/yd^3 (\$10 to \$33/m^3); the cost for materials ranged from \$ 5 to \$12/yd^3 (\$6 to \$16/m^3). Generally, the larger the site, the lower the overall cost since mobilization/demobilization of the equipment is a significant portion of the injection costs. If additional injections should be needed, they typically cost less than the initial injection (D12764K, p. 115).

Information Sources

D12764K, Burke and Rhodes, November/December 1993

D12584I, Burke and Rhodes, 1995

T0457

Kemron Environmental Services, Inc.

Bioremediation — Soil and Groundwater

Abstract
Kemron's bioremediation technology is designed to remediate contaminated soil and groundwater in conditions approaching a closed-loop system. According to the vendor, the technology is capable of treating contamination from petroleum products, solvents, nonhalogenated volatiles and semivolatiles, benzene, toluene, ethylbenzene, and xylene (BTEX), polynuclear aromatics, and organic acids.

The technology is not applicable for contaminants that are not biodegradable, such as chlorinated solvents, pesticides, and herbicides, polychlorinated biphenyls (PCBs), metals, and certain inorganics. Also, the cleanup time can take up to several months to complete, depending on the type of contaminant.

Technology Cost
The vendor estimates the price for remediation using their bioremediation technology between \$10 and \$15/yd^3. This price estimate may not include all costs associated with the treatment such as excavation, permits, and treatment of residuals. According to the vendor, factors having a significant effect on the price include characteristics of the soil, initial and target contaminant concentrations, and depth of the contamination (D102932, p. 14).

Information Source

D102932, VISITT 4.0, 1995

T0458

Kenox Technology Corporation

Wet Air Oxidation

Abstract
The Kenox wet air oxidation process operates under elevated temperature and pressure to oxidize organic and oxidizable inorganic materials in aqueous solution. Organic compounds are oxidized to low-molecular-weight compounds such as carboxylic acids, carbon dioxide, and water. The developer claims that the technology can facilitate the removal and recovery of heavy metals or catalysts and can produce recoverable thermal energy when treating high-strength waste streams.

Wet air oxidation is applicable to aqueous waste streams containing organic and oxidizable inorganic materials where:

- The chemical oxygen demand (COD) of the influent ranges from 1 to 20%.
- The waste stream is too toxic for biological treatment and too dilute for incineration. Or
- Destruction of toxic material and COD reduction can increase the capacity of an existing treatment facility.

The vendor indicates the technology can treat waste streams containing solvents, petroleum distillates, chlorinated solvents, pesticides and herbicides, as well as phenolic wastes, pulping liquors, municipal sewage, and industrial sludges.

The Kenox wet air oxidation technology is commercially available through authorized distributors.

Technology Cost

According to information from Kenox, the capital costs for a wet air oxidation system is approximately $11 million. Assuming a 400 liter/min wastewater stream is treated to 99% removal efficiency for one year, the unit cost is estimated to be approximately $0.0125 per metric ton. All cost estimates are based on 1998 U.S. dollars (D18704W, p. 3).

Information Source

D18704W, GLOBAL Techs, 1998

T0459

King, Buck Technologies, Inc.

HD CatOx System

Abstract

The HD CatOx™ system treats vapor emissions contaminated with halogenated volatile organic compounds (VOCs). HD CatOx is a trade acronym for the term "halohydrocarbon destruction catalytic oxidation" system. This system is based on the use of a proprietary catalyst for a fixed-bed oxidation process.

According to the vendor, this technology is commercially available in systems ranging in capacity from 100 cubic feet per minute (cfm) to over 2000 cfm.

The prototype HD CatOx system was permitted by the California South Coast Air Quality Management District (AQMD) in 1990, and operating results met the conditions of the AQMD's permit to operate.

According to the vendor, HD CatOx has the following advantages:

- Has a low operating temperature.
- Minimized the use of supplemental fuels.
- Has low daily operating costs.
- Virtually eliminated the production of NO_x
- Does not produce toxic products of incomplete combustion polychlorinated dioxins and furans.
- Generates no hazardous wastes.
- Destroys contaminants.

The proprietary HD catalyst operates at lower temperatures than incineration and other types of catalysts. This reduces the production of toxic products of incomplete combustion (PICs) to negligible levels as well as minimizing energy demands.

Technology Cost

An HD CatOx system having a capacity of 200 standard cubic feet per minute (scfm) is priced at approximately $150,000 (1992 dollars). Daily operating costs for utilities and the caustic for hydrochloric acid neutralization are about $200 (1992 dollars). The preheater's monthly operating cost would be $220. Monthly electrical costs for the extraction blower and refrigeration unit would be approximately $800 (D135319, p. 530; D13108Y, p. 50).

With chlorinated organic compounds, it is important to know the daily emission limits for hydrogen chloride. Regulations across the United States vary with respect to this acidic gas, and acid-gas neutralization following catalytic oxidation may or may not be required. This factor has a significant impact on the cost competitiveness of the process (D13106W, p. 4).

According to the vendor, HD CatOx, because of its low operating temperature and the integral heat exchanger, minimizes the need for supplemental fuel (D14851Q, p. 3).

Information Sources

D13106W, Buck and Freidel, 1994

D13108Y, Buck and Seider, 1991

D135319, Buck et al., 1992

D14851Q, King, Buck Technology, vendor literature

T0460

King, Buck Technologies, Inc.

MultiMode Combustion

Abstract

King, Buck Technologies, Inc.'s, MultiMode™ combustion (MMC) system treats volatile organic compound (VOC) emissions from soil vapor extraction (SVE) operations. The sequential operation of a thermal oxidizer (ThermOx) followed by a catalytic oxidizer (CatOx) is the basic concept of the MMC system. The CatOx technology is discussed in a separate technology summary (T0780).

This technology is currently commercially available.

For thermal oxidation, due to the need to heat the mixture of air and VOC to a minimum temperature of about 760°C, the cost of auxiliary fuel to sustain the desired operating temperature can be relatively high. Energy savings can be provided by a product gas-to-feed gas heat exchanger. But safety considerations (the fear of autoignition of the influent gas in the heat exchanger) then impose an upper limit to the VOC concentration that can be fed to the thermal oxidizer.

Unless controlled, the temperature inside the catalytic oxidizer could rise above 600°C, a temperature considered an upper limit by consideration of catalyst stability and structural strength of lightweight reactors.

Another limitation on the use of catalytic oxidation is the susceptibility of the catalysts to various deactivators or poisons, although according to the vendor the phase out of the use of volatile lead alkyls as antiknock agents in U.S. gasoline, catalyst poisoning is today rarely encountered.

Technology Cost

The MultiMode combustor (MMC) comes in two sizes. The MMC-5 unit consists of a 100-standard cubic foot per minute (scfm) thermal oxidizer and a 100-scfm catalytic oxidizer. The MMC-6 unit consists of a 150-scfm thermal oxidizer and a 200-scfm catalytic oxidizer.

The base price of the MMC-5 unit is $56,200 (1992 dollars). For the thermal oxidizer portion of the MMC-5 unit, maximum daily fuel cost for natural gas would be $60 (1992 dollars), and maximum daily fuel cost for propane would be $95 (1992 dollars). For the catalytic oxidizer portion of the MMC-5 unit, the maximum daily electrical cost would be $22 (1992 dollars), assuming an electric preheater rated for 36 kW at 480 V is used at 240 V. The daily cost to operate the vacuum/compression unit for the MMC-5 is $6 (1992 dollars), assuming a 3-hp electric motor drawing 2.3 kW is used.

The base price of the MMC-6 unit is $73,800 (1992 dollars). For the thermal oxidizer portion of the MMC-6 unit, maximum daily fuel cost for natural gas would be $90 (1992 dollars), and maximum daily fuel cost for propane would be $143 (1992 dollars). For the catalytic oxidizer portion of the MMC-6 unit, the maximum daily electrical cost would be $48 (1992 dollars), assuming an electric preheater rated for 20 kW at 240 V is used. The daily cost to operate the vacuum/compression unit for the MMC-6 is $18 (1992 dollars), assuming a 10-hp electric motor drawing 7.5 kW is used.

These costs are based on the assumption that the system is running on fresh air. This assumption means that the supplementary fuel supply would be supporting the thermal oxidizer entirely, and the preheater on the catalytic oxidizer would be running 24 hr a day. These are highly unlikely scenarios that would occur only if the British thermal unit (Btu) content of the vent gas was zero. In reality, operating costs vary with the volatile organic compound (VOC) concentration in the vent gas, making actual fuel and preheater costs significantly lower than what is presented here (D13108Y, pp. 45, 48).

Information Source

D13108Y, Buck and Seider, 1992

T0461

Kinit Enterprises

Trozone Soil Remediation System

Abstract

According to the technology developer, the Trozone soil remediation system is a closed-loop, ex situ process that uses a mixture of technologies that include ozonolysis, reverse osmosis, and enzymes.

The technology treats soil and natural sediment (both ex situ), nonmunicipal sludge, and solids (e.g., slag).

According to the technology developer, the technology treats petroleum-contaminated soils, hazardous wastes, heavy metals, polychlorinated biphenyls (PCBs), semivolatile organic compounds (SVOCs), volatile organic compounds (VOCs), polynuclear aromatic hydrocarbons (PAHs), and pesticides.

The Trozone soil remediation system cannot treat fluorides.

RIMS was unable to contact the vendor.

Technology Cost

The technology developer claims that the estimated cost for using the Trozone soil remediation system is $30 to $1000 per ton of waste treated (D102921, p. 23).

According to the technology developer, the soil remediation system was used in full-scale cleanups at the following three sites with the indicated total project costs:

- NASA Space Station (Huntsville, AL)—$3,500,000
- FMC Plant (Anniston, AL)—$65,000
- Fish hatchery (Milford, KS)—$95,000 (D102921, pp. 10, 15, 20)

Among the factors that affect the cost of the technology are:

- Waste quantity
- Soil characteristics
- Target contaminant concentration

- Amount of debris contained in waste
- Residual waste characteristics
- Labor rates
- Utility/fuel rates
- Initial contaminant concentration
- Contamination depth
- Depth to groundwater
- Moisture content of soil
- Site preparation
- Waste handling/preprocessing (D102921, p. 23)

Information Source

D102921, VISITT 4.0

T0462

Klean Earth Environmental Company (KEECO, Inc.)

KB-1

Abstract

Klean Earth Environmental Company (KEECO) has developed the KB-1™ system for the stabilization and immobilization of hazardous metals in aqueous solutions. According to the vendor, chemical reagents are mixed with the contaminated water and lock the targeted metals into an inert silica matrix (D16239K, p. 1). The sludge is nontoxic and may be left in place or disposed of off-site (D18686B, p. 2). KB-1 is one of a group of technologies developed by KEECO using similar approaches to treating materials contaminated with heavy metals. KB-SEA (RIMS Technology T0103) is used to treat solids contaminated with heavy metals. META-LOCK™ (RIMS Technology T0464) is used to treat materials contaminated with radionuclides or heavy metals. KB-1 is commercially available.

According to the vendor, advantages of KB-1 over traditional lime include the following:

- Enhanced (almost instantaneous) solids settling rate.
- Reduced volume of precipitated solids requires disposal.
- Chemical stability of final waste form under aerobic and anaerobic conditions.
- Final waste form is resistant to changes in pH.
- Reduced startup costs.
- KB-1 acts as a strong oxidant, oxidizing ferrous to ferric iron without the need for aeration or additional chemicals.

While metal contaminants are isolated in the silica grains during treatment, the long-term retention of metals in this matrix is unknown. Other additives may be required to process certain contaminants. KB-1 does not destroy microorganisms.

Technology Cost

According to the vendor, the setup of all systems in a KB-1 plant typically costs $150,00 to $250,000. A lime treatment plant can cost $4 to $6 million. Average costs of the KB-1 system are $3.00 to $5.00 per 1000 gal. The vendor claims the KB-1 process can cost below one cent per gallon for treatment of acid mine drainage. Costs depend upon metal load and the cleanup goals. Disposal costs may be eliminated by leaving treated sludge in place (D18686B, p. 1; D202879, p. 1; D202868, p. 8).

At the Bunker Hill Site in Kellogg, Idaho, treatment costs were approximately $0.005/gal of treated water or $25,000 a month (D202686, p. 1). The cost of the KB-1 was less than one tenth of a cent per liter of water treated. Product cost at the Wheal Jane Mine in the United Kingdom was less than $0.003/gal (D202868, p. 30; D202879, p. 1).

Information Sources

D17040B, Espenson, 1997
D17041C, Daniels, 1997
D18686B, Daniels, 1997
D18804Z, Mitchell, 1998
D202686, PAYDIRT, 1999
D202868, KEECO, 1999
D202879, Wheaton, 1997

T0463

Klean Earth Environmental Company (KEECO, Inc.)

KB-SEA

Abstract

Klean Earth Environmental Company (KEECO) has developed the KB-SEA™ system for the stabilization and immobilization of hazardous metals in soils. The process mixes chemical reagents with contaminated soils to lock the targeted metals into a silica matrix. The technology can be used on sludges, soils, and mine tailings (D16226F, p. 13). KB-SEA is one of a group of technologies developed by KEECO using similar approaches to treating materials contaminated with heavy metals. KB-1™ (RIMS Technology T0462) is used to treat aqueous solutions contaminated with heavy metals. META-LOCK™ (RIMS Technology T0464) is used to treat materials contaminated with radionuclides and heavy metals. The technology is commercially available.

The vendor states that KB-SEA has the following advantages:

- Reduces treatment cost by treating contaminated material in situ.
- Is a permanent solution to heavy-metal contamination.
- Is energy efficient.
- Prevents future acid generation and leaching of toxic heavy metals.
- Creates a rich substrate for plant growth.
- Returns soil to its natural state.

KB-SEA requires a soil moisture of at least 20% to be effective. KB-SEA cannot trap arsenic under basic conditions and requires acidic to neutral conditions to form a stable matrix. Overapplication of KB-SEA may result in the formation of basic solutions because of KB-SEA's pH of 13.8.

Technology Cost

The normal cost for treatment of soils is under $100 per ton treated. The vendor claims that this is less expensive than excavation and hauling and eliminates the need for hazardous waste disposal and the associated liability (personal communication, James Roma, KEECO, 9/97).

In Delaware, KEECO used KB-SEA to treat 2000 yd^3 of sediments contaminated with lead. The total cost of the project was $200,000. The project manager estimated that off-site treatment and disposal of the sediments would have cost $300,000 and that disposal in a hazardous landfill would have cost $750,000 (D202824, p. 1; D20296A, p. 3).

Information Sources

D202824, KEECO, 1999
D20296A, KEECO, 2000

T0464

Klean Earth Environmental Company (KEECO, Inc.)

META-LOCK

Abstract
Klean Earth Environmental Company (KEECO) has developed the META-LOCK™ system for the stabilization and immobilization of materials contaminated with radioactive wastes or heavy metals. The process works using a precipitation–flocculation–chemisorption technology that surrounds the targeted contaminant with a silica encapsulation. META-LOCK is one of a group of technologies developed by KEECO using similar approaches to treating materials contaminated with heavy metals. KB-1 (RIMS Technology T0462) is used to treat aqueous solutions contaminated with heavy metals, and KB-SEA™ (RIMS Technology T0463) is used to treat solids contaminated with heavy metals. META-LOCK technology has been evaluated in laboratory tests and is commercially available.

The vendor claims the META-LOCK technology is capable of substantially reducing the volume of waste, decreasing the cost of transportation and disposal. According to the vendor, the process is highly cost effective, efficient, and permanent, producing compounds that will not leach or degrade.

Although META-LOCK removes radionuclides from contaminated media, it produces a secondary waste stream. The product sludge is radioactive and must be handled and disposed of accordingly. Other additives may be required to process certain contaminants. META-LOCK does not destroy microorganisms.

Technology Cost
No available information.

T0465

Klohn-Crippen Consultants, Ltd.

ChemTech Soil Treatment Process

Abstract
Klohn-Crippen Consultants, Ltd., has developed the ex situ ChemTech soil treatment process for the removal of heavy metals and organic contaminants from contaminated soil and sediment. The ChemTech process uses two mechanisms to remove contaminants: physical scouring of the soil particle surface and chemical leaching of the contaminants from the soil particles. Processing takes place using a three-phase fluidized bed. The technology has been evaluated in pilot-scale

trials using a portable unit. The vendor is developing a full-scale capability and plans to have a commercial trailer-based mobile plant in operation some time in 1999.

The vendor claims the following advantages of ChemTech technology:

- Rapid process kinetics result in faster and cheaper cleanups.
- High capacity process requires only a small footprint.
- Treatment removes a wide range of contaminants.
- Treatment minimizes cost of cleanups due to lower labor costs, lower capital costs, and lower setup and tear-down costs.
- Treatment produces lower volumes requiring disposal, and the solids filter cake formed may allow for disposal as nonhazardous waste.

The vendor states that performance of ChemTech technology is limited when the contamination is intrinsic to the soil (as is the case with metal particulate, sandblasting grit, or mine tailings). Performance of the technology is hindered when treating sediments containing a large percentage of fine particulate. The U.S. Navy notes the following additional limitations of the ChemTech process:

- Compared to land-filling and stabilization methods, the equipment required is more complex.
- Specialized operator training is needed.
- Compared to stabilization, a longer treatment time is required.
- On-site space is required to store pre- and posttreatment media and residuals.
- Additional treatment may be needed to meet local or state regulatory requirements (D18250N, p. 2).

Technology Cost

In 1998, the vendor claimed that treating a soil with 70% fine particulate materials to residential standards costs about \$110 per metric ton. In contrast, treating a soil with 10% fine particulate materials using risk-based cleanup costs about \$30 per metric ton. These estimates are based on a 375-metric-ton-per-day operation at a site containing 20,000 metric tons of contaminated soil. According to the vendor, total cleanup costs including cost of ownership and indirect costs would range from \$50 to \$80 (Canadian dollars) per metric ton of contaminated soil. If physical separation was used to achieve project goals, costs could potentially drop below \$40 (Canadian dollars) per metric ton treated (D17735Z, pp. 11–12).

In 1997, Stephenson et al., estimated that the total cleanup costs for treating 20,000 tons of soil using a 250-ton/day ChemTech unit would be approximately \$100 per ton. For the purposes of this estimate, the soil is assumed to consist of 20% oversized particulate and 10% fine particulate. The residence time of solids in the treatment unit is assumed to be 15 min (D177360, p. 9). Costs are summarized in Table 1.

The factors that affect the technical and economic performance of ChemTech soil treatment process technology include the following: soil type (sand versus clay); contaminant (metals, petroleum compounds, particulate metals, etc.) type, form, and concentration; cleanup objectives (residential, industrial, or risk-based); and the scale of the project. These factors determine optimum operating conditions, process kinetics, the quantity of residuals, and the operating costs (D177360, p. 9).

Information Sources

D177360, Stephenson et al., 1997

D17735Z, Stephenson and Yan, 1998

TABLE 1 ChemTech Estimated Total Cleanup Costs for a Metals-Contaminated Soil[a]

Cost Element: Items Included	Cost per Ton ($U.S.)
Pretreatment	1.90
Sampling, treatability testing, analysis, mobilization of equipment, spill containment, travel, setup	
Soil treatment	37.50
Soil handling labor, soil treatment labor, chemicals, utilities, supplies	
Posttreatment	22.55
Treatment of soil cake, water treatment, equipment decontamination, storage, disposal, disposal of water treatment sludge, disposal of used personal protective equipment, takedown, demobilization, site restoration, report	
Cost of ownership	26.20
Amortization of capital, equipment rental, profit	
Indirect costs	10.10
Administration, marketing, accounting, legal, insurance, office	

Source: Adapted from D177360.
[a] No general allowance was made for site restoration, since this cost is highly variable. The cost of purchasing, installing, and commissioning a 250-ton/day mobile ChemTech soil treatment plant is estimated to be approximately $1.5 million (U.S. dollars, 1997).

T0466

Krudico, Inc.

Ion Exchange Technology for the Removal of Nitrate and Perchlorate

Abstract
Krudico, Inc., develops ion exchange units for the removal of inorganic contaminants such as nitrate and perchlorate. Ion exchange technologies use resins or other materials to selectively remove contaminants from dilute waste streams. In the case of nitrate and perchlorate, the contaminants are exchanged for chloride ions attached to the resin material. Krudico's system can be designed for either one-time use, or the spent resin can be regenerated. Regeneration produces a concentrated waste stream, which reduces final disposal or treatment costs of the contaminated material.

Krudico, Inc., offers several types of systems for the removal of nitrate. The vendor tested a pilot-scale perchlorate removal unit at the U.S. Department of Energy's (DOE's) Lawrence Livermore National Laboratory in 1999. The system is also commercially available.

Exchange resins may have an affinity for other ionic contaminants such as sulfates. Waste streams with these competing ionic contaminants may have lower removal efficiencies and these treatment systems may require more frequent resin regeneration or disposal. Ion exchange treatment does not destroy targeted contaminants. In some cases, waste disposal costs may render the technology cost prohibitive.

Technology Cost
Bench- and pilot-scale tests were used to prepare cost estimates for Krudico, Inc., ion exchange system treatment of groundwater contaminated with nitrate and perchlorate at the DOE's Lawrence Livermore National Laboratory. Data were provided for three options: nitrate removal only, perchlorate removal only, and removal of both nitrate and perchlorate. Estimates were

TABLE 1 Summary of Costs (in Dollars) Associated with Various Treatment Alternatives at Lawrence Livermore National Laboratory

Option	Capital Costs	Setup/Installation Costs	Operation and Maintenance (O & M) Costs	Cost per Gallon Treated (Overall)
Nitrate removal only	\$15,700	\$25,600	\$258,400	\$0.15
Perchlorate removal only	\$2,300	\$4,300	\$37,200	\$0.02
Removal of nitrate and perchlorate	\$17,700	\$27,600	\$263,300	\$0.16

Source: Adapted from D20493D.

based on a system treating approximately 1,839,600 gal of contaminated groundwater at a rate of 3.5 gallons per minute (gpm). Nitrate removal was estimated to cost \$0.15/gal, perchlorate removal was estimated to be \$0.02/gal, and a combined removal system was estimated to cost \$0.16/gal (D20493D, p. 12).

Researchers concluded that ion exchange removal of nitrate was cost prohibitive at the Livermore site because of the high cost of waste disposal. The perchlorate-only alternative with nitrate removal using another technology was the most cost-effective solution. Perchlorate disposal costs under this option were \$350/year, and minimal maintenance of the treatment unit would be required (D20493D, p. 12). The cost estimates are summarized in Table 1.

Information Source

D20493D, Burge and Halden, 1999

T0467

KSE, Inc.

AIR-II Process

Abstract

The Adsorption Integrated Reaction (AIR-II) process is a destructive photocatalytic oxidation (PCO) process for the treatment of gas-phase waste streams that can operate successfully at low concentrations of contaminants and at a low energy cost. In the process, ultraviolet (UV) light illuminates a proprietary catalyst at room temperature, and produces hydroxyl radicals, which destroy organic compounds by oxidation. Very few by-products are created by the process, and many contaminants are broken down into harmless carbon dioxide and water.

Potential applications for this technology include the treatment of airstreams contaminated with volatile organic compounds (VOCs) from air stripping, soil vapor extraction, industrial air emissions, and for the cleaning of air in closed environments. PCO is best suited for waste streams with low concentrations of contaminants, and with low to medium flow rates. The AIR-II process can operate consistently in conditions where flow rates and VOC concentrations are highly variable, even intermittent.

The process can be integrated with existing technologies, such as thermal desorption, air stripping, or soil vapor extraction.

The technology is applicable to chlorinated and nonchlorinated VOCs; methyl tertiary butyl ether (MTBE); dichloroethylene (DCE), trichloroethylene (TCE), and tetrachloroethylene (perchloroethylene, PCE); dichloroethane (DCA); vinyl chloride; alcohols; ethers; ketones; and halogenated and nonhalogenated paraffinic, olefinic, aliphatic, and aromatic hydrocarbons. It is very effective at treating benzene, toluene, ethylbenzene, and xylene (BTEX) compounds and any oxygenate, such as acetone or isopropanol.

A great deal of research has been performed on this technology; it has been used several times in the field, and the AIR-II process is currently commercially available.

Technology Cost

The cost of any photocatalytic oxidation (PCO) technology, including the Adsorption Integrated Reaction (AIR-II) process, is dependent on a number of variables. These include photoefficiency, ultraviolet intensity, contaminant concentration, and the desired level of destruction of contaminants.

In 1994, the National Renewable Energy Laboratory [NREL, a national laboratory of the U.S. Department of Energy (DOE)] performed a cost comparison of PCO versus other air pollution control technologies. It was determined from this study that the cost per standard cubic foot per minute (scfm) increased with contaminant concentration but fluctuated little with flow rate. For treatment of VOC concentrations above 1000 parts per million (ppm), the PCO systems became expensive relative to other technologies (D130905, p. 3).

In 1996, the Los Alamos National Laboratory (LANL, also a DOE laboratory) made similar observations, noting that while capital costs rise slowly with contaminant concentrations, the cost of materials, operation and maintenance, and labor remains constant (DA, p. 59).

Information provided by the vendor, KSE, Inc., gives several examples of costs for the AIR process. The first example is for a system treating a 2500-scfm airstream from a groundwater stripper, operating 8000 hr per year, with contaminant levels from 3 to 30 ppm. A system such as this would cost $95,000 in capital costs, and would cost an additional $6000 per year to operate, assuming electrical costs of $0.06/kWh (D14369L, p. 3).

KSE, Inc., recently designed an AIR system for a contact lens degreasing operation. For this system treating a 200-scfm airstream contaminated with 1000 to 2000 ppm of mixed hexanes, the capital cost was $51,000, and the operating cost was estimated at $5900/year (at $0.07/kWh) (D14369L, p. 4).

An AIR system for emissions control in the expandable polystyrene industry required a capital investment of $175,000, with annual operating costs of $7500. This unit was designed to treat a 3000-scfm airstream with contaminant levels ranging from 200 to 3500 ppm (D14369L, p. 5).

Based on these examples, the costs for AIR-II systems are in line with LANL's observations. They have a flexible capital cost that is proportional to the scale of the application. Operational costs are consistently very low, typically around $6000 annually.

Information Sources

D130905, Turchi et al., 1994

D12104Q, Cummings and Booth, 1996

D14369L, KSE, Inc., date unknown

T0468

KVA

C-Sparger System

Abstract

The C-Sparger™ is an in situ chemical oxidation technology designed to remove halogenated solvents such as perchloroethylene (PCE), trichloroethylene (TCE), and dichloroethene (DCE)

from contaminated groundwater and soil. The microfine bubbles produced by the Spargepoints™ extract the dissolved contaminant from groundwater, while the encapsulated ozone destroys it. This technology is available in single-, double-, and triple-well assemblies. C-Sparger technology has also been applied to sites contaminated with total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, and xylene (BTEX).

C-Sparger technology is patented (U.S. Patents 5,855,775 and 6,083,407) and additional patents are pending. C-Sparger technology is commercially available and has been used in the full-scale remediation of sites in the United States and The Netherlands.

Some advantages of chemical oxidation follow:

- Destroys organic contaminants.
- Operates more quickly than other techniques (in months rather than years).
- Lower treatment costs.

Chemical oxidation technology limitations include:

- Less cost effective at sites with high contaminant concentrations.
- Reagent application rates must be carefully controlled due to the energetic nature of the process reactions.
- Compounds in the contaminated media can interfere with contaminant oxidation.

Technology Cost

In June 2001, the Interstate Technology Regulatory Cooperation (ITRC) Work Group published technical and regulatory guidelines for in situ chemical oxidation of contaminated soil and groundwater. The guidance document contains information that can be used in preparing cost estimates for chemical oxidation technologies like the C-Sparger system. For more information, please see D22442A, Appendix D.

Although many of the costs for chemical oxidation technologies will be site specific, chemical costs will generally average 15 to 30% of the total remediation costs. Factors that influence chemical costs will include the chemical oxygen demand (COD) of the contaminated media, pH, the size of the site, and initial contaminant concentrations (D22442A, pp. 19, D-1).

Spargepoints for the C-Sparger cost \$45 to \$75 for small-diameter Spargepoints, \$95 for 2-inch by 30-inch Spargepoints, and \$475 for 4-inch by 60-inch Spargepoints. For a three-well system with a single C-Sparger panel, the estimated cost per well is approximately \$5500, and the estimated cost to operate it is approximately \$15 per month (D150447).

C-Sparger technology was used in two cities in Kansas to treat groundwater contaminated with TCE. The source of contamination for these sites were dry cleaning establishments. Cost information for these full-scale applications are summarized in Table 1.

Each C-Sparger consists of a master unit and one or more in-well assemblies and below-well Spargepoint assemblies. Each master unit can operate up to a total of 6 sparge assemblies. Additional shallow wells are also recommended at 5, 10, and 30 ft from the sparge wells. The prices for each part are shown in Table 2 (D18103D, p. 6).

A demonstration of C-Sparger technology for the remediation of a deep plume of dissolved chlorinated solvents in groundwater was conducted in Utrecht, The Netherlands, in 1997. The C-Sparger system consisted of an in-ground sparge point, an in-well sparge point, a packer and a fluid pump, four monitoring wells, previously installed miniwells, and a fire well. The cost of \$35,000 for this project included placing the C-Sparger unit on a site, a trailer to house the work area and monitoring equipment, a generator system for the blower unit, drilling, enclosing part of the site, laboratory sampling, and report preparation. The cost of installation for the pre-existing wells was not included (D18766A, p. 23).

TABLE 1 Cost Information for C-Sparger System Ozone Technology

Site Name	Treatment Type	Individual Cost Items Listed	Total Cost
Dry cleaning site, Garden City, Kansas	Ozone	\$31,000—system components \$25,000—injection and monitoring well installation \$25,000—maintenance and repairs	\$81,000
Dry cleaning sites, Hutchinson, Kansas	Ozone	\$50,000—system components \$30,000—injection and monitoring well installation \$25,000—additional SVE[a] components \$17,000—controller installation \$11,000—operation, maintenance, and repairs	\$133,500

Source: Adapted from D22442A.
[a] SVE, soil vapor extraction.

TABLE 2 1997 C-Sparger System Prices

Item	Includes	Cost
Master unit	Ozone generator, compressor, controller, power supply for in-well pumps	\$10,500
In-well unit	Pneumatic packer, submersible pump, Spargepoint, well-cap assembly, tubing, and cable	\$2,000
Below-well unit	Spargepoint, support column, fitting for 4-inch casing, tubing	\$295
Rental of master unit	One-month minimum	\$2,000

Source: D18103D, p. 6.

Information Sources

D150447, McCulloch Environmental Equipment Sales, web page

D18103D, K-V Associates, Inc., 1997

D18766A, U.S. EPA, 1998

D22442A, Interstate Technology and Regulatory Cooperation Work Group, 2001

T0469

Kvaerner Metals

Resin-in-Pulp/Carbon-in-Pulp Processes

Abstract
The Resin-in-Pulp (RIP) and Carbon-in-Pulp (CIP) processes were developed for the ex situ treatment of soils, sediments, dredgings, and solid residues that are contaminated with organic

and inorganic materials. These technologies are based on the principles of resin ion exchange and resin or carbon adsorption of contaminants from a leached soil–slurry mixture. The process consists of leaching contaminants from their matrix in a soil washing step, followed by a reclamation step using activated carbon or ion exchange.

Depending on the reagents, surfactants, and extraction agents used during treatment, this technology has a wide range of potential applications. Potential applications of the RIP/CIP processes are for the remediation of materials contaminated with heavy metals, inorganics, and organic materials such as chlorinated solvents, pesticides, and polychlorinated biphenyls (PCBs).

This technology is not currently commercially available.

Technology Cost
No information available.

T0470

Lambda Bioremediation Systems, Inc.

Bioremediation

Abstract
Lambda Bioremediation Systems, Inc., applies a variety of natural, site-specific acclimated microbes to bioremediate contaminated soil and groundwater in situ. Lambda draws from an extensive culture collection and a unique database of microbial information to formulate a blend of microbes suited for each specific site. This technology is currently commercially available for full-scale site remediation.

Lambda has successfully applied bioremediation in the following scenarios:

- Acid mine drainage
- Heavy-metals contamination
- Hydrocarbon contamination (gasoline, oils, diesel fuels)
- Cutting oils and aqueous metal working fluids
- Industrial wastewater
- Agricultural waste and runoff
- Cyanide contamination
- Desulfurization of coal fines
- Chlorinated aliphatics
- Pesticides
- Semivolatile organic compounds (SVOCs)
- Denitrification and reductive dechlorination
- Landfill leachate

Technology Cost
There is no available information regarding the costs associated with field application of this technology.

T0471

Lawrence Livermore National Laboratory

Carbon Aerogel Capacitive Deionization of Water

Abstract
Carbon aerogel capacitive deionization (CA-CDI) is an ex situ technology under development by Lawrence Livermore National Laboratory (LLNL), which uses carbon aerogel electrodes to

remove salt and other ionic impurities from aqueous streams. In the process, voltage is applied to multiple pairs of electrodes. Ionic species are attracted to electrodes with the opposite charge and are electrostatically held in place until the charge is reversed to purge the contaminants.

Extensive testing has been performed with solutions of NaCl and $NaNO_3$. Test results indicate the CA-CDI system can effectively remove heavy metals including copper, manganese, zinc, cadmium, cobalt, chromium, lead, and uranium from aqueous process streams and natural waters.

LLNL and Far West Group, Inc., signed a licensing agreement in January 1997 to commercialize the CA-CDI process. CDI Technologies Partnership was created in November 1997 as an independent entity to develop and patent practical implementations of the basic technology. The technology is not yet commercially available for remediation applications.

Potential applications for CA-CDI technology include the purification of boiler water for fossil and nuclear power plants, volume reduction of liquid radioactive waste, treatment of agricultural wastewater containing pesticides and other toxic compounds, creation of ultrapure water for semiconductor processing, treatment of wastewater from electroplating operations, desalination of seawater, and removal of salt from water for agricultural irrigation.

Using the CA-CDI process is expected to consume less energy per unit of water purified than conventional methods, does not use costly membranes or pumps, operates at ambient temperature, and is resistant to chemical attack.

The CA-CDI system may not be suitable for the treatment of streams that contain over 2000 ppm of total dissolved solids and is best suited for treating relatively dilute streams. The technology is not well suited for the treatment of organic contaminants.

Technology Cost

The commercialization of carbon aerogel technologies has been slow due to high production costs. Although the costs associated with a complete treatment system have not yet been determined, researchers believe that the life span of the carbon aerogel electrodes themselves will be the primary determinant of this technology's economic viability (D16251G, p. 3).

Information Source

D16251G, Lawrence Livermore National Laboratory, 1995

T0472

Lawrence Livermore National Laboratories

Destruction of Polychlorinated Biphenyls Using High-Energy Ionizing Radiation

Abstract

Lawrence Livermore National Laboratories (LLNL) has researched the use of high-energy ionizing radiation to destroy polychlorinated biphenyls (PCBs) in solvent mixtures. The technology uses an electron beam device or a cobalt-60 radiation source to generate free radicals in the liquified waste. These radiolytically produced free radicals interact with the PCBs, dechlorinating the compounds. The technology has undergone bench-scale proof-of-concept experiments using PCB-contaminated potting compound found in some fluorescent light ballasts.

Researchers claim that high-energy ionizing radiation could be more economical than existing treatment technologies for treating fluorescent light ballasts.

Only liquified wastes have been successfully destroyed by high-energy ionizing radiation. The technology has only been evaluated in bench-scale tests.

Technology Cost

In the initial bench-scale testing of high-energy ionizing radiation treatment technology, researchers stated that to reduce the level of PCBs to meet federal requirements, a 15-MegaRad radiation dose was required. Such a dosage could be obtained using a 10-million-electron-volt (MeV) commercially available accelerator used to irradiate and sterilize prepackaged medical products. Operating and capital cost projections indicated that treatment costs for PCB-contaminated fluorescent light ballasts would be approximately $3.35 per ballast (D14069C, p. 4).

Researchers later stated that if the contaminated material was removed from the metal ballasts, energy requirements would be reduced. This would enable a system of less than 10 MeV to be used. It was estimated that treatment costs using this lower energy system could be as low as $0.50 per ballast (D175580, p. 23).

Information Sources

D14069C, Matthews et al., 1996
D175580, Hazardous Waste Consultant, 1996

T0473

Lawrence Livermore National Laboratory

Direct Chemical Oxidation

Abstract
Direct chemical oxidation (DCO) is an ex situ treatment technology that uses acidified ammonium or sodium peroxydisulfate solutions to oxidize and destroy organic solids, liquids, and sludges. Acidified peroxydisulfate is one of the strongest oxidants available. It is equal in strength to ozone and exceeded only by fluorine and oxyfluorides. The process is designed to operate within the aqueous phase at low temperatures and ambient pressure.

The U.S. Department of Energy's (DOE's) Lawrence Livermore National Laboratory (LLNL) developed the DCO technology. LLNL has an operating commercialization agreement with Perma-Fix Environmental Services, Inc. Perma-Fix planned to incorporate DCO into its Perma-Fix Process technology (RIMS2000 technology summary number T0600). According to the LLNL in 1998, Perma-Fix was marketing the DCO technology with "little to no recognition" of LLNL. The DOE believes that DCO is ready for pilot-scale demonstrations in the field.

According to the DOE, some advantages of the DCO technology are that it:

- Oxidizes most types and quantities of organic materials.
- Operates at low pressures and ambient temperatures.
- Produces no dust and does not volatilize metals.
- Treats a wide range of waste matrices.
- Minimizes secondary wastes.
- Uses an oxidant that is commercially available.

Large quantities of bulk organic matter or combustible debris will require large amounts of oxidant and generate large quantities of hydrogen sulfate by-product. The amount of oxidant required to treat a waste stream will increase if a significant amount of water is present. The presence of chloride ion in the waste stream will slow the rate of organic oxidation by competing for the available oxidant. Contaminant oxidation is not effective when the peroxydisulfate ion concentration is less than 0.3 molar. The oxidation of organics is an exothermic reaction.

Technology Cost
The cost of organics destruction using DCO will depend heavily on the nature of the waste stream being treated. Easily oxidized organics in neat form will be the least expensive to treat.

Significant amounts of water in the waste stream (over 50%) will increase the amount of peroxydisulfate required because water is also capable of reducing this oxidant. Heavily chlorinated organics will require more peroxydisulfate due to the oxidation of organochlorine to free chlorine gas. If the waste matrix contains a substantial amount of nonhazardous organics, then more peroxydisulfate is required due to the competing oxidations of these matrix components (D18455Y, p. 4).

The DCO oxidant may be electrochemically recycled. If the expended oxidant is not recycled, then the cost of DCO is estimated to be $79.00/kg of carbon destroyed. If the peroxydisulfate is recycled, then the energy cost is $4.00/ kg of carbon destroyed. The total cost of a DCO system using recycled oxidant was estimated to be $10.40/kg of carbon destroyed. These estimates include the cost of oxidant at $0.73/lb, the cost of electricity at $0.06/kWh, labor costs at $120 per day, and capital costs of $100,000. The full-scale unit was estimated to treat 50 kg of carbon per day with an online availability of 80%. The estimates do not include the additional costs of working in a nuclear environment, pretreatment, or stabilization and disposal of the final product (D18455Y, pp. 4, 5; D20886Q, p. 14; D20844G, p. 37; D21204U, p. 2).

In June 2001, the Interstate Technology Regulatory Cooperation (ITRC) Work Group published technical and regulatory guidelines for in situ chemical oxidation of contaminated soil and groundwater. The guidance document contains information that can be used in preparing cost estimates for chemical oxidation technologies. For more information, please see D22442A, Appendix D.

Although many of the costs for chemical oxidation technologies will be site specific, chemical costs will generally average 15 to 30% of the total remediation costs. Factors that influence chemical costs will include the chemical oxygen demand (COD) of the contaminated media, pH, the size of the site, and initial contaminant concentrations (D22442A, pp. 19, D-1).

Information Sources

D18455Y, Balazs et al., date unknown

D20844G, Cooper and Balazs, 1998

D20886Q, Cooper et al., 1999

D22442A, Interstate Technology and Regulatory Cooperation Work Group, 2001

D21204U, U.S. EPA, 2000

T0474

Lawrence Livermore National Laboratory

Hot-Recycled-Solid (HRS) Retorting Process

Abstract

The hot-recycled-solid (HRS) retorting process, a technology originally developed by Lawrence Livermore National Laboratory (LLNL) for retorting oil shale, has been modified by LLNL for use as thermal treatment process for inorganic and organic liquid wastes and sludges. LLNL has demonstrated thermal decomposition of sodium nitrate in liquid waste and believes that the technology also should be effective for thermal treatment (or pyrolysis) of organics from liquid wastes and sludges and for the destruction of high explosives and liquid gun propellants. Because the technology uses a moving bed of hot ceramic spheres as the heat transfer mechanism, it avoids sticking and agglomeration of liquid waste, which can be a problem for other thermal treatment technologies.

The HRS process has been demonstrated on a small pilot scale (1 to 5 kg/hr) but needs further research and development before it is ready for commercialization or application at an actual site. Currently, the HRS process is only designed for treating liquid wastes, specifically

liquid mixed (hazardous and radioactive) wastes from Hanford, Washington. In this application, the HRS process is proposed as a first-stage treatment process to remove certain hazardous inorganic and organic components and water from the waste; it would produce a radioactive solid residue requiring further treatment such as vitrification. In addition, gas exiting the process must be scrubbed to remove nitrogen oxides. The HRS process also has potential to effectively pyrolyze organic materials from such wastes but would require additional treatment or destruction technologies for the organic compounds volatilized during pyrolysis.

Technology Cost

No information was available on the costs of using the HRS retorting process to treat hazardous or mixed wastes. Cost estimates for the full-scale application of the HRS process for oil shale retorting may be found in D120672.

Information Source

D120672, Cena, 1993

T0475

Lawrence Livermore National Laboratory

In Situ Microbial Filter

Abstract

The in situ microbial filter consists of a permeable wall of trichloroethylene- (TCE)-degrading microorganisms, which is designed to be placed in the subsurface to intercept a contaminant plume. In this design, contaminants would be degraded by microorganisms in the filter as the plume passively flows through the biofilter with the natural hydraulic gradient. The filter would be formed by direct injection of microorganisms into the subsurface to form a wall or by injecting the microorganisms into an emplaced sand trench.

Success of the in situ microbial formation is predicted, upon the development of a methanotrophic microorganism that can attach to the subsurface and degrade contaminants for an extended period of time in the absence of added nutrients. The microorganism used by Lawrence Livermore National Laboratory (LLNL) is *Methylosinus trichosporium* (OB3b). Studies on its growth requirements revealed conditions that would enhance the expression and activity of the enzyme responsible for TCE degradation—soluble methane monooxygenase. In laboratory experiments OB3b has maintained TCE degradation activity in the absence of added nutrients for up to one month.

Laboratory development of the in situ microbial filter has been completed. According to LLNL, the key engineering design parameters have been measured under controlled conditions, and scaled laboratory experiments have demonstrated the success of the approach. A field demonstration of the biofilter concept was conducted at a contaminated site in Chico, California.

According to the vendor, the technology is most economical for large plumes with fast-flowing groundwater and TCE concentrations of less than 10 parts per million (ppm). The minimum ambient criteria for the technology include:

- Matrix pore size of >10 μm, permitting bacterial transport
- Groundwater pH from 6 to 8
- TCE concentrations less than 25 ppm
- Dissolved oxygen levels ranging between 0.37 and 1.28 ppm, depending on the contaminant and concentration

Technology Cost

According to the technology developer, the total cost for using the in situ microbial filter technology is approximately half of the estimated pump-and-treat cost, while involving only about 10% of the usual volume of groundwater used in pump-and-treat remediation (D152103, p. 1).

Based on 1997 data, the estimated cost of a permeable reactive barrier (PRB) system ranged from approximately $405,000, corresponding to $1400 per 1000 gal of groundwater extracted, to $585,000, corresponding to $225 per 1000 gal of groundwater extracted. The capital costs ranged from $373,000 to $500,000 and operation and maintenance (O & M) costs ranged from $32,000 to $85,000. Treatment barrier costs included system construction, installation, monitoring, and analytical costs. Costs may vary due to differences in the subsurface matrix, thickness, and composition of the barrier. Data were provided by Geomatrix, the U.S. Navy, and the U.S. Coast Guard (D18882D, pp. 133, 145).

Information Sources

D152103, R. B. Knapp, 1995

D18882D, Federal Remediation Technologies Roundtable, 1998

T0476

Lehigh University

Ground Rubber as a Reactive Permeable Barrier Medium

Abstract

Researchers at Lehigh University have investigated the ability of ground tire rubber to sorb organic compounds such as benzene, toluene, ethylbenzene, and xylene (BTEX) to determine the feasibility of using the rubber as the sorbent media in reactive permeable barrier systems. Thus far, no field-scale work has been performed on this technology. Both batch and packed-bed column tests have been conducted. All information is from the researchers and has not been independently verified.

Technology Cost

No available information.

T0477

Lehigh University

Hybrid Inorganic Sorbent (HISORB)

Abstract

Lehigh University is researching Hybrid Inorganic Sorbent (HISORB) technology, which combines ion exchange and adsorbance mechanisms to remove low concentrations of dissolved heavy metals from contaminated water and wastewater. HISORB contains ferrihydrite, a composite form of iron, and akermanite, a crystalline silicate phase. The akermanite neutralizes aqueous-phase hydrogen ions. The neutralization process enhances the sorption capacity of ferrihydrites to remove metals. According to the developer, HISORB is a by-product that is produced during the reclamation process of steel. The developer also indicates that this technology has the ability to remove toxic metals from aqueous solutions with a pH between 3.0 and 11.0. The technology can also be regenerated and reused.

The technology was tested at least at one site in 1996. Results from field demonstrations of the technology are not currently available.

Technology Cost
According to the developer, HISORB ion exchange material is less expensive than the more common chelating ion exchange resins (D16178O, p. 356; D17038H, p. 2195).

Information Sources

D16178O, Gao and Sengupta, 1994
D17038H, Gao et al., 1995

T0478

Lewis Environmental Services, Inc.

Soil-Leaching and ENVIRO-CLEAN Technologies

Abstract
The Lewis Environmental Services (Lewis) combined soil leaching and ENVIRO-CLEAN process schemes can possibly eliminate the need to dispose of chromated copper arsenate(CCA-)-contaminated soil (a hazardous waste) and permit the recovery of valuable metals (such as copper and chromium). The soil-leaching process involves sulfuric acid leaching, water washing, and air drying of the soil. The two-step, patent-pending ENVIRO-CLEAN process, the second phase of the treatment, uses a granulated activated carbon system followed by an electrolytic recovery system, to recover heavy metals from the leaching stream and the wash water.

The Lewis ENVIRO-CLEAN process removes and recovers metals such as chromium, copper, nickel, mercury, lead, zinc, iron, and cadmium and has effectively demonstrated that it can treat a matrix of multiple metals in a single stream with positive results. The process treats wastes from wood preserving, metal finishing, mining, surface and groundwaters. The two-step process uses granular-activated carbon and electrolytic metal recovery to yield a salable metallic by-product.

According to Lewis soil-leaching process can possibly be applied to solid wastes generated by the wood preserving and metal plating industries, battery waste sites, and urban lead sites. Potential remedial applications for the ENVIRO-CLEAN process include groundwater treatment, Superfund leachate treatment, and metals removal from wet scrubber systems. Commercializing the ENVIRO-CLEAN technology could result in the recovery and recycling of such metals as copper, chromium, zinc, nickel, and mercury.

According to the vendor, the advantages of the combined Lewis treatment process over traditional treatment processes for CCA wastes are as follows:

- Treated soils pass TCLP criteria and the soils can be replaced on site.
- Treatment by-products are not disposed as a hazardous waste.
- Land disposal of large volumes of soil is eliminated.
- Heavy metals are recovered by the ENVIRO-CLEAN process and can be reused by industry.
- Closed-loop recovery of valuable chemicals and water can be performed by wood treating sites or chemical manufacturers.

Technology Cost
The cost for traditional waste treatment averages \$3.00/lb in comparison to \$1.00/lb for the ENVIRO-CLEAN process, according to Lewis Environmental Services, Inc. (Lewis). This shows a cost reduction of more than 66% (D135035, p. 1).

The annual operating cost for a tin mill plant with a new waste treatment plant is more than $1,450,000, with more than $700,000 in sludge disposal costs. Lewis asserts that, in comparison, the ENVIRO-CLEAN process treatment cost includes chromium recovery valued at more than $190,000 and water savings valued at more than $50,000 per year. According to Lewis, a large-scale ENVIRO-CLEAN system complete with electrolytic recovery has an annual operating cost of less than $800,000 a year (D135035, p. 1).

The vendor claims that the elimination of sludge generation in the ENVIRO-CLEAN process (heavy-metal material and waste treatment chemicals) produces substantial energy and recoverable metal savings. Metal recycling eliminates the use of high-energy virgin materials for refining, yielding substantial energy decreases. Using chromium as the recovered metal, the total savings is $128 per ton of sludge (D135035, p. 1).

Information Source

D135035

T0479

Limnofix, Inc.

Limnofix In Situ Sediment Treatment (LIST)

Abstract

Limnofix In situ Sediment Treatment (LIST) technology is offered by Limnofix, Inc., a Golder Associates Company. The technology allows for the in situ treatment of contaminated sediment in surface waters. LIST enhances bioremediation of organic contaminants; oxidizes sediments to control odor, nutrient release, or sulfide toxicity; and produces stable marine sediment surfaces via consolidation and flocculation.

The technology uses patented equipment to directly inject treatment compounds into sediments. The equipment can be mounted on boats, barges, or floats and can be propelled by boat, tug, or a winch from shore. A key system component is a specially designed boom arm that is dragged behind the vessel. The boom arm contains a series of nozzles, tines, and injection ports.

According to the vendor, bench-scale and pilot-scale tests have been performed in Canada and Asia. LIST is currently being used for a full-scale remediation of sediments contaminated with coal tar from a former manufactured gas plant (MGP) site in Massachusetts. The technology is commercially available.

According to the vendor, LIST offers the following advantages:

- Treats large areas of contaminated sediments.
- Uses simple equipment and requires no excavation or disposal of contaminated sediments.
- Costs less than dredging.
- Can be used during navigational dredging activities.

LIST technology has the following limitations:

- It cannot remediate metals, although the presence of metals does not appear to limit the biodegradation of organic contaminants.
- The effectiveness of treatment may be reduced by low temperatures.
- Sites with rocky bottoms are difficult to treat with this technology.
- In general, biodegradation technologies may have difficulty meeting site closure requirements.

Technology Cost

In 1995, the vendor estimated that the cost of LIST treatment would range from \$20 to \$50/m^3. Factors listed as having an impact on treatment cost include (in decreasing order of importance) initial contaminant concentrations, the quantity of waste to be treated, site cleanup goals, setup/tear-down costs, labor costs, utility costs, amount of debris associated with the waste, site preparation costs, and the use of barges/tug boats (D10290Z, p. 29). In 2001, the vendor stated that LIST treatment costs would vary according to the treatment area and treatment goals and would range from \$35 to \$75/m^2 (D22682O, p. 2).

The cost of dredging and disposal of 3000 m^3 of sediment in 1988 at the Dofasco site in Hamilton Harbor cost more than \$600,000. After dredging, the bottom was still highly contaminated, and "hot spots" of contamination were present (D13825K, pp. 1072, 1074). It was estimated that dredging the hot spots in Hamilton Harbor would cost approximately \$20 million, while cleanup of the rest of the contaminated sediment by excavation would cost approximately \$4 billion (D20043R, p. 8). Based on pilot-scale testing, researchers estimated that LIST treatment of 5000 m^2 of contaminated sediment at the Hamilton site cost \$250,000, or approximately \$32/m^3 (D10290Z, p. 11). It was estimated that 15 to 30% of the projected treatment costs would be associated with chemical costs (D20043R, p. 10).

It is estimated that bioremediation of sediments using LIST would cost 20% less than dredging and storage in a confined storage facility (D13764O, p. 201).

Some caution may be needed when evaluating in situ technologies for the remediation of sediments. In situ treatment of sediments may be less cost-effective than ex situ methods because the treatment level for in situ methods is not uniform and in some cases project goals cannot be met throughout the site (D20043R, p. 6).

Information Sources

D13764O, Murphy et al., 1995
D13825K, Murphy et al., 1994
D10290Z, VISITT 4.0, 1995
D20043R, Renholds, 1998
D22682O, U.S. EPA, 2001

T0480

Linatex, Inc.

Bergmann Soil/Sediment Washing Technology

Abstract

The Bergmann USA soil/sediment washing system is a waste minimization technique designed to separate or partition soils and sediments by grain size and density. In this water-based volume-reduction process, hazardous contaminants are concentrated, using physical and chemical methods, into a small residual portion of the original volume. The technology is based on the following premises: (1) almost all of the contaminants of interest in the sediment are either partitioned or concentrated into two fractions consisting of organic materials (i.e., leaves, roots, twigs, bark, etc.) and fine particles (called fines), and (2) contamination of the larger, granular particle fraction (clean sand and larger) is small.

The technology is commercially available and has been successfully applied for full-scale treatment and remediation of organic and inorganic contaminated material occurring at hazardous waste sites and within bays, harbors, and river areas. Bergmann USA was closed for business in 1998. However, the soil/sediment washing technology is still available from their parent company, Linatex, Inc.

Technology Cost

Remedial contractor cost estimates for the Bergmann USA soils/sediment washing process range from $75 to $125 per ton, depending on the total amount of material to be processed. The average cost per ton of treated soil depends on the feed rate and the fines content of the soil.

Detailed cost information for the Bergmann USA soil/sediment washing system can be found in a paper entitled "Application of Full-Scale Soil/Sediment Washing for Remediation of Superfund, RCRA, DOE & DOE Hazardous Waste Sites" (Georgia Water & Pollution Control Association, pp. 4, 8–9). Site-specific cost information for the Saginaw Bay and Toronto Harbour sites can be found in the case studies section under the heading "Operating Costs" (D11959P, p. 4).

Information Sources

D11959P, Traver and O'Brien, February 1995

D10426X, EPA Applications Analysis Report, September 1995

D10059U, EPA Applications Analysis Report, April 1993

D11953J, HazTECH News, June 27, 1991

T0481

Lockheed Martin Corporation

Acid Extraction

Abstract

The Lockheed Corporation, now Lockheed Martin, has designed, constructed, and operated batch and continuous ex situ treatment facilities for acid extraction of contaminants. This technology involves the solubilization of contaminants, followed by the isolation of soluble elements into appropriate forms. The goal of this technology is to minimize the volume of hazardous and radioactive constituents for disposal. Physical separation techniques may be used as pretreatment steps.

According to the vendor, full-scale processes have been employed to remediate depleted uranium and uranium process residues. Systems have also been designed for treatment of natural uranium-contaminated materials. Processes for the treatment of materials contaminated with multiple heavy metals have been designed and demonstrated. RIMS was unable to determine the commercial availability of this technology.

Technology Cost

No available information.

T0482

Lockheed Martin Corporation

TRUclean Soil Washing System

Abstract

The TRUclean soil washing system is a patented, ex situ modular process that uses soil washing, size fractionation, and gravimetric separation techniques to remediate soils contaminated with radionuclides and heavy metals. The technology developer, Lockheed Martin Corporation, claims

that the technology treats soil (ex situ) and potentially treats the following media: nonmunicipal sludge, solids (e.g., slag), and natural sediment.

The developer asserts that the technology has been used in the following industries: battery recycling, chloro-alkali manufacturing, electroplating, metal ore mining and smelting, petroleum refining, inorganic chemical manufacturing, semiconductor manufacturing, rubber manufacturing, landfill sites, and uranium mining.

All information is from the vendor and has not been independently verified.

Technology Cost

No available information.

T0483

Lockheed Martin Energy Systems, Inc.

Soilex Process

Abstract

The Soilex process is an ex situ process for extracting polychlorinated biphenyls (PCBs) from soil, sediments or sludge. The soil is mixed with water and an organic solvent to dissolve and remove the PCBs.

This technology was developed by Lockheed Martin Energy Systems, Inc., but there are no plans to commercialize it. Bench- and pilot-scale testing was conducted in 1984 at the Department of Energy (DOE) Y-12 Plant in Oak Ridge, Tennessee. Most of the testing used kerosene and water for extraction, but dimethyl formamide was also tested.

During treatment, both the solvent and water are recycled. According to the results of pilot-scale testing, more than 90% of the PCBs in soil can be extracted by the process. Spent kerosene will need to be removed from soil before disposal.

Technology Cost

The estimated cost for the Soilex process is \$856 to \$913/m^3 of treated soil. This estimate includes dredging, transportation, treatment, and redeposition of the treated sediments (D13464F, p. 67).

Operation and equipment costs are minimized by keeping kerosene-to-soil ratios as low as possible (D13464F, p. 63).

Information Source

D13464F, U.S. EPA, undated

T0484

Longbore, Inc.

Horizontal Drilling

Abstract

Horizontal drilling is a contaminant extraction technology designed to access areas that are difficult for vertical wells to reach due to surface obstructions such as buildings, landfills, and lagoons. The technique was originally developed as an oil extraction method. Environmental horizontal wells are used in correlation with other remediation techniques, such as pump-and-treat

remediation, in situ remediation, or air sparging. Horizontal wells can also serve as a sampling conduit to monitor site conditions.

The vendor states that horizontal wells offer the following advantages:

- Require installation of fewer wells compared with vertical wells, minimizing cost per wellhead and per-foot drilling costs.
- Allow more complete contact with the contaminant plume.
- Access areas unreachable by vertical wells.
- Minimize risk of cross-contamination due to hydraulic channeling because fewer bore holes penetrate the regions of low permeability between aquifers.
- Produce higher contaminant yields by increasing hydraulic gradient, reducing the time required for remediation.

According to the vendor, the geologic formation is a limiting factor in the depth at which horizontal drilling is performed. Formations with vertical fractures that can extend to the surface can pose limitations because drilling fluid can breakout at the surface. Horizontal drilling only improves access to the contaminants and must be combined with a remediation technology.

Technology Cost

In 1995, the vendor estimated that the waste treatment costs would range from $75 to $500/ft. Well/wellscreen length and subsurface lithology at a site significantly affect installation costs. This estimate may not include all indirect costs (D10159X, p. 8). Most horizontal wells are installed at private industry sites, so performance information and cost data are not commonly available (D22909O, p. 2).

Horizontal drilling and well installation costs are quite variable. Factors that can influence costs include the depth of installation, site geology, site-specific institutional requirements, well design, and well materials (D18187X). The type of drilling fluid used and the size of the drilling team will also influence installation costs. The U.S. Department of Energy (DOE) provided a rough estimate that the installation of one horizontal well cost about the same as five vertical wells. However, the operation and maintenance (O & M) costs for a horizontal well were estimated at one-third the cost of five vertical wells (D21201R, p. 1).

In 1990, Drilex Systems, Inc. (now part of Longbore, Inc.), installed two horizontal wells at an automotive manufacturing facility in Taylor, Michigan. The first well was 575 ft long. The well had a screened length of 412 ft and it was installed to a depth of 30 ft. The second well was 475 ft long and had a screened length of 157 ft. This well was installed at a depth of 35 ft. The approximate cost for both wells was $218,000 (D22909O, p. B-47).

Information Sources

D10159X, VISITT 4.0, 1995

D22909O, GWRTAC, 2002

D21201R, U.S. EPA, 2000

D18187X, Kaback, 1997

T0485

Los Alamos National Laboratory

High-Gradient Magnetic Separation for Radioactive Soils and Process Wastes

Abstract

High-gradient magnetic separation (HGMS) is a physical separation technology that can be used to separate constituents with positive magnetic susceptibility [e.g., iron and iron compounds (ferromagnetic); uranium, plutonium, and other actinide contaminants (paramagnetic)]

from soils and process wastes. HGMS uses intense magnetic fields to accomplish the separation. By applying superconducting systems to magnetic separators, fields up to 8 tesla (T) can be achieved. HGMS is capable of concentrating the actinides in a soil or waste to form a low-volume, actinide-rich stream for subsequent processing and a high-volume, actinide-lean stream for direct discard as industrial waste. HGMS is able to treat particles from approximately 90 to 0.1 μm in diameter. The majority of radioactive components in contaminated slurries have been found to concentrate in this fine particle range.

Although HGMS has been used commercially on a large scale for more than 2 decades for some applications, it has been tested only at the bench-scale level for remediation of radioactive-contaminated soils and process streams. This technology is not currently commercially available for radioactive solid or liquid decontamination.

A high content of magnetic components in the soil could preclude removal of magnetic contaminants.

Technology Cost

No available information.

T0486

Los Alamos National Laboratory

Uranium Heap Leaching Technology

Abstract

The uranium heap leaching technology is an ex situ adaptation of a 20-year-old heap leach mining (i.e., of gold, silver, and copper) technique used to treat soil. Each soil/contaminant chemical treatment combination is unique and must be developed separately. The equipment required for field-scale uranium heap leaching is basically the same as the equipment used in standard mining practices.

The vendor claims that the technology will treat uranium and possibly thorium. At this point, the technology has only been bench tested. The vendor hopes, however, that once the heap leaching technology is fully developed, it will be used to remove metals chemically (uranium in this case) from soil without damaging the soil. With some modification, the process can also be used to remove volatile organic compounds from soil by ex situ soil venting.

According to the vendor, another possible application of the technology is to support remedial treatments using surfactants, mild acids or bases, or special chelating agents. Heap leaching can be used with ex situ bioremediation techniques, where biological agents actively convert or degrade toxic substances. Contaminated soil can be placed in a heap and nutrients, oxygen, and other bioreactor stimulants can be added to increase the efficiency of the biological process.

The technology could reduce excavation costs by eliminating hauling, once it is proven that the technology can successfully reduce contaminants to acceptable levels. Once the technology is developed, other advantages could include:

- on-site cleanup
- conservation of expensive repository space at a licensed disposal site
- reduced liabilities and costs from long-term monitoring, isolation, and habitat protection
- soil relocated in an attempt to provide a permanent solution

Additional limitations associated with the heap leaching technology are:

- The heap leaching technology is not economical at small scale, i.e., at 1000 yd^3 (800 m^3).

- The technology could have problems selectively extracting contaminants without removing other materials and without destroying the soil or rendering it unusable.

Technology Cost

The developer asserts that, based on a study of gold heap leaching costs, it is currently estimated that heap leaching can clean soil at the Fernald Environmental Management Project (FEMP) site (Fernald, Ohio) soil for less than $150/yd^3, and possibly for less than $100/yd^3. The larger the quantity of soil to be cleaned up, the smaller the cost per unit volume. In the case of the FEMP soil, the soil volume would be 4,000,000 yd^3 (3,000,000 m^3). In comparison, batch reactor leaching is estimated to cost approximately two to three times as much, based on an economic study of gold leaching. The cost for excavating, hauling, and reburying the contaminated soil will be approximately $200/ft^3 ($5400/yd^3). These additional costs are attributed to the use of a waste generator, in addition to continuous monitoring of the reburied waste (D13569N, p. 3).

The Pacific Northwest National Laboratories estimated that the total cost estimate for batch leaching of contaminated soils is $30 to $500 per ton of treated soil and for heap leaching of contaminated soils is $10 to $150 per ton of treated soil. These costs include excavation, capital, and operating and maintenance costs. This estimate is based on costs for leaching of precious metals from ores in the mining industry (D18769D, p. 5).

Among the variables that affect the operations costs for the uranium heap leaching process are leaching reagents, leachate regeneration materials, electrical power, and personnel. Startup costs include equipment requirements such as a leaching pad, a reagent distribution system, a sump, a leachate regeneration system, surge capacity for leachate and regenerated leaching reagent, earth moving equipment, possibly agglomerating equipment, and possible crushing equipment (D13568M, p. 5).

During the pilot-scale treatability tests conducted at the FEMP site, disposal costs for off-site disposal were very low: less than $350 for uranium waste, compared to $700,000 for 1000 tons (900 metric tons) of contaminated soil [assuming disposal costs of $700/ton for off-site disposal (D13201U, p. 116)].

The following cost information includes all actual costs to date from the developer, Los Alamos National Laboratory, plus all future cost estimates for Los Alamos and FEMP through the completion of the pilot-scale test at FEMP (D13569N, p. 6):

- Actual costs to date—$360,000
- Estimate to completion—$2,775,000
- Estimate at completion—$3,046,000
- Operations and maintenance costs of the technology
- Cleanup of soil by a mining subcontractor—4,000,000 yd^3 (3 million m^3) × $150/yd^3 = $600,000.

The cost information does not include excavation or administrative costs incurred by FEMP (e.g., decommissioning, regulatory, institutional oversight, and future liability costs) (D13569N, p. 6).

Information Sources

D13568M, 1994

D13569N, September 18, 1994

D13201U, U.S. DOE, date unknown

D18769D, U.S. DOE, date unknown

T0487

Louisiana State University

Colloidal Gas Aphron

Abstract
Louisiana State University is researching applications of colloidal gas aphron (CGA) technology for soil flushing sites contaminated with light non-aqueous-phase liquids (LNAPLs) and heavy metals. CGAs are micro gas bubbles encapsulated by a thin surfactant film. The bubbles are approximately 65% air by volume and vary in diameter from 25 to 150 μm. These bubbles possess the same charge (if any) as the surfactant material from which they are created; so it is possible to generate anionic, nonionic, or cationic aphrons. CGA technology can be used in situ to remove LNAPLs from soils by soil washing techniques or to improve the efficiency of bioremediation. The technology has been the focus of bench-scale experiments and is not commercially available.

The researcher claims that CGA technology has several advantages over traditional soil washing technology, including:

- Mobilizes hydrophobic organic compounds more effectively.
- Offers potential applications in the removal of inorganic constituents, such as heavy metals, that conventional soil washing technology lacks.
- Lessens the density of the treated soil, making it easier to contain dense compounds that might otherwise sink out of the treatment area after mobilization.
- Reduces the amount of surfactant required for treatment.
- Allows for possible applications as a delivery system for delivering nutrients, oxygen, or microorganisms for bioremediation.

CGA technology does not destroy wastes. The technology is used to improve extraction efficiency of targeted contaminants or to enhance bioremediation.

Technology Cost
No available information.

T0488

Lynntech, Inc.

Electrokinetic Remediation of Contaminated Soil

Abstract
Lynntech, Inc.'s (Lynntech's), electrokinetic remediation of contaminated soil technology is an in situ soil decontamination method that uses an electric current to transport soil contaminants. According to Lynntech, this technology uses both direct current (DC) and alternating current (AC) electrokinetic techniques (dielectrophoresis) to decontaminate soil containing heavy metals and organic contaminants. A nonhomogeneous electric field is applied between electrodes positioned in the soil. The field induces electrokinetic processes that cause the controlled, horizontal, and/or vertical removal of contaminants from soils of variable hydraulic permeabilities and moisture contents.

The developer claims that the technology treats sandy soils and compact soils such as clays, in addition to other low-permeability soils where hydraulic pumping (pump and treat) may be ineffective for contaminant and reagent removal. The technology is not commercially available.

According to the developer, the technology has the following advantages:

- Does not require excavation or off-site transport of contaminated material.
- Processes soils with high or low moisture contents.
- Can treat varying soil textures (including soils with low hydraulic permeability such as clays).
- Combines easily with other remediation technologies.
- Uses environmentally benign chemical additives in the treatment process.
- Controls contaminant flow direction easily.

It may be difficult to estimate the time that will be required to remediate a site using this technology. Heterogeneities or anomalies in the soil will reduce removal efficiencies. Extreme pHs at the electrodes may also inhibit the system's effectiveness. Electrokinetic remediation is most efficient when the pore water has low salinity. Electrokinetic remediation requires sufficient pore water to transmit the electrical charge. Contaminant and noncontaminant concentrations effect the efficiency of the process.

Technology Cost
Initial and target contaminant concentrations, concentration of nontarget ions, soil characteristics and moisture content, quantity of waste, depth to contamination, residual waste handling and processing, site preparation requirements, and electricity and labor rates have a significant effect on the unit price of electrokinetic remediation technologies (D19938G, pp. 16, 17).

Information Source

D19938G, Interstate Technology and Regulatory Cooperation Work Group, 1997

T0489

M.L. Chartier, Inc.

Therminator

Abstract
The Therminator is an ex situ, commercially available medium-temperature portable thermal desorption/destruction unit for soils and clays contaminated with petroleum hydrocarbons. According to the vendor, the Therminator offers an alternative to landfilling petroleum-contaminated soils.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0490

M4 Environmental, L.P.

Catalytic Extraction Process

Abstract
M4 Environmental, L.P., has developed the catalytic extraction process (CEP) for treating hazardous wastes. In CEP technology, a bath of molten metal is used as a catalyst to dissociate

materials into elemental forms. The vendor states that once the wastes have broken down, reactions occur to convert the materials into economically useful components. The system typically operates at temperatures of approximately 1500°C and pressures of approximately 1 atmosphere. Feeds normally produce metal, ceramics, and off-gases. The off-gases typically consist of volatile metals, hydrogen, hydrochloric acid, and carbon monoxide.

Molten Metal holds 41 patents on CEP and quantum-catalytic extraction process (QCEP) technologies, covering more than 200 application and disclosures. On December 3, 1997, Molten Metal Technology, Inc., filed for reorganization under Chapter 11 of the Federal Bankruptcy Code.

The vendor claims that CEP technology has several advantages:

- Treats a wide variety of materials.
- Reduces the volume of radioactive material in mixed waste operations.
- Produces recyclable products.

Some influent waste streams require pretreatment. Extensive off-gas treatment is required. The system does not eliminate the need for a combustion process because the product gases would be oxidized in a separate unit

Technology Cost

According to the vendor, costs of the CEP depend on the quantity of waste, moisture content of the influent, feed type, feed properties, treatment rate, operating pressure, utility and fuel rates, and location. In 1994, it was estimated that CEP processing would cost \$100 to \$250 per ton. Another estimate placed treatment costs between \$100 and \$500 per ton. Recovered materials could be sold, lowering treatment costs. Prices for recovered products can range from \$80 per ton for some off-gases to \$4000 per ton for condensed-phase products (D115479, p. 602; D12014P, p. 2166; D22939U, p. 6).

In 1996, the U.S. Department of Energy's (DOE's) Integrated Thermal Treatment System Study (ITTS) examined the processing and disposal costs of 19 thermal treatment systems. CEP was determined to have the lowest costs at a estimated \$8.98/lb (D18612T, p. 38).

Information Sources

D115479, Chanenchuk et al., 1994

D12014P, Nagel et al., 1996

D18612T, Office of Science and Technology, 1998

D22939U, U.S. EPA Reachit, undated

T0491

MACTEC, Inc.

Chemical Oxidation (ChemOx) Process

Abstract

MACTEC, Inc., offers a chemical oxidation (ChemOx) process, a transportable technology that removes volatile and semivolatile organic contaminants, sulfur compounds, and odors from wastewater. Contaminant-specific oxidants are added to the contaminated water as it passes through a proprietary venturi blending system. The contaminants are destroyed by process solutions, and the treated water can then be discharged. According to the vendor, the technology can be applied to sites where organic contaminants are absorbed on particles in a water stream,

to petroleum tank bottoms, storm water runoff, deicing fluids and first flushes at airports, remediation wastewater effluent, and to contaminated wastewater streams. The technology is commercially available.

MACTEC claims the following advantages using the ChemOx system:

- Small, portable, closed system that can treat large volumes of water.
- Can be retrofitted in existing facilities.
- Solids in wastewater don't interfere with treatment.
- System offers simplified permitting and is cost effective.

All information is from the vendor and has not been independently verified.

Technology Cost

The vendor states that its chemical oxidation (ChemOx) technology is very cost effective because no off-gas stream is formed, can be retrofitted in existing facilities, and can treat large volumes of wastewater (D17707V, p. 2).

The cost of ChemOx treatment depends on the specific application. Factors that influence cost include specific contaminants to be removed, concentration of contaminants in the effluent, amount or flow rate of water to be treated, discharge requirements, and geographical location. The vendor states that they will provide cost estimates for specific applications (D17705T, p. 4).

Information Sources

D17707V, MACTEC, Inc., undated vendor web page

D17705T, MACTEC, Inc., undated vendor literature

T0492

Magnum Water Technology

CAV-OX Cavitation Oxidation Technology

Abstract

The Magnum Water Technology (Magnum) CAV-OX™ process is a patented, combination of hydrodynamic cavitation, ultraviolet (UV) radiation, and hydrogen peroxide that oxidizes organic contaminants in water. According to the vendor, the system is a cost-effective method of removing organic contaminants from aqueous waste streams or groundwater without releasing volatile organic compounds (VOCs). The technology is commercially available.

Hydrodynamic cavitations in flowing liquids result from pressure variations in the CAV-OX system. Vapor-filled cavities form when the pressure is reduced to a critical value without a change in ambient temperature.

According to the vendor, the CAV-OX technology treats contaminants such as halogenated solvents, phenol, pentachlorophenol (PCP); pesticides; trichloroethene (TCE); polychlorinated biphenyls (PCBs); explosives; benzene, toluene, ethylbenzene, and xylene (BTEX); methyl tertiary butyl ether; bacteria and virus strains; and cyanide.

The CAV-OX process consists of either of two configurations: the CAV-OX I low-energy process or the CAV-OX II high-energy process. The CAV-OX I process effectively treats contaminants such as gasoline or TCE, while more complex wastes, such as PCP, require the use of the CAV-OX II process. The CAV-OX process generally reduces contaminant levels by 95 to 99.99%.

The CAV-OX technology offers the following advantages when compared with other technologies that treat volatile organic carbons (VOCs) in water: effective at low concentrations, no air emissions, no secondary waste, and VOCs are destroyed.

Free product, suspended solids, and highly turbid waste streams lower UV reactor efficiency. The CAV-OX process does not treat metals. It may, however, oxidize metallic ions or reduce metallic salts while destroying organic contaminants. The disadvantages of the CAV-OX process include high energy consumption, not cost effective at high contaminant concentrations, and the process mechanisms are not well documented.

Technology Cost

Magnum Water Technology (Magnum) estimates the cost of using the CAV-OX process to be approximately half of the cost of other advanced UV oxidation systems and substantially less than carbon adsorption (D107222, p. 102).

The vendor states that capital costs for the CAV-OX I are $61,000 and include $58,000 for equipment and $3000 for installation (D20012K, p. 6).

According to the vendor, operating costs have ranged from $1.62 to $1.93 (October 1993 dollars) per 1000 gal of water containing organic contaminants. These costs included operating chemical usage, power consumption by UV lamps and by the centrifugal pump, maintenance allowance costs, and amortization of capital equipment over 5 years (D105486, p. 63).

Typical operating costs (presented in October 1993 dollars) for the CAV-OX process are as follows (D105486, p. 39):

- CAV-OX cavitation chamber only—about $0.50 per 1000 gal of treated water
- CAV-OX cavitation chamber with low-energy UV radiation and hydrogen peroxide—about $2 per 1000 gal of treated water
- CAV-OX cavitation chamber with high-energy UV radiation and hydrogen peroxide—about $4 per 1000 gal of treated water

The CAV-OX technology demonstration at Edwards Air Force Base (Edwards) Site 16 in California examined 12 separate cost categories using the CAV-OX treatment of contaminated groundwater at a Superfund site. This analysis examined costs for the CAV-OX I low-energy configuration and the CAV-OX II high-energy configuration using flow rates of 10 and 25 gallons per minute (gpm). Costs (in October 1993 dollars) for each configuration are summarized in Table 1 (D105486, p. 3).

TABLE 1 CAV-OX Process Cost Summary (October 1993 Dollars)

CAV-OX Configurations	CAV-OX I Low-Energy Process Costs ($)		CAV-OX II High-Energy Process Costs ($)	
Capacities	10 gpm	25 gpm	10 gpm	25 gpm
Capital	314,500	342,500	314,500	342,500
CAV-OX process direct capital	48,000	64,000	48,000	64,000
Annual O & M	71,000	78,000	75,000	86,000
Groundwater remediation per 1000 gal (4000 liters)	30	13	31	14
CAV-OX process direct per 1000 gal (4000 liters)	10	5	11	5

Source: From D105486.

TABLE 2 CAV-OX I Annual Operating Cost

	Cost
Chemicals	\$1,741
Maintenance	\$5,114
Capital costs amortized over 5 years	\$11,600
Total	\$22,047
Treatment cost	\$1.67/1000 gal

Source: From D20012K.

Table 2 shows the annual operating costs associated with a CAV-OX I for a waste stream containing 50 parts per million (ppm) to 50 parts per billion (ppb) of benzene (D20012K, p. 7).

At a typical groundwater remediation site contaminated with 350 ppb of benzene, 340 ppb of toulene, 34 ppb of benzene, 270 ppb of xylenes, 33 ppb of trichloroethene (TCE), 33 ppb of tetrachloroethene (PCE), and 10 ppb of chloroform, the vendor estimates that operating costs for a 10-gpm CAV-OX I system would be \$10,965 per year. If contaminant concentrations were changed to 2 ppb for benzene and toluene, 40 ppb for benzene, 82 ppb for xylenes, 33 ppb for TCE, 10 ppb for PCE, and 5 ppb for chloroform, the vendor predicts that costs would decrease to \$7468 per year (D20012K, p. 7).

According to the vendor, a 20-gpm CAV-OX I system treated cyanide-contaminated water at a steel mill in South Korea for \$1.93 for each 1000 gal (D20014M, p. 7; D105486, p. 69).

A 2.3-liter/min CAV-OX I system and a 5.3-liter/min CAV-OX™ II system operated at a site contaminated with 1500 to 2000 micrograms per liter (mcg/liter) of TCE and 250 to 500 mcg/liter of benzene. The remediation cost \$3.80/m^3 for the CAV-OX I and \$4.07/m^3 for the CAV-OX II (D19079Y, p. 3–16).

The cost to remove 99.9% of 190 mg of total petroleum hydrocarbon (TPH) per liter (mg/liter) using a 38-liter/min CAV-OX I unit was \$0.47/m^3 (D19079Y, p. 3–16).

At a site contaminated with 1800 mcg/liter of TCE, 450 mcg/liter of DCE, 53 mcg/liter vinyl chloride, and 11 mcg/liter of PCE, operating costs for a CAV-OX I system were \$0.32/m^3 (D19079Y, p. 3–17).

Information Sources

D105475, EPA Technology Demonstration Summary, March 1995

D105486, EPA Applications Analysis Report, May 1994

D107222, EPA SITE Demonstration Program, October 1995

D19079Y, U.S. EPA 1998

D20012K, vendor literature, 1997

D20014M, vendor literature, 1997

D20015N, MTBE Research Partnership, 1998

T0493

ManTech Environmental Corporation

ElectroChemical GeoOxidation (ECGO)

Abstract

ElectroChemical GeoOxidation (ECGO) is an in situ technology designed to remediate organic-contaminated soil and groundwater as well as liquid and sludge waste streams. The process works by applying an electrical current to probes driven into the ground at contaminated sites.

According to the vendor, ECGO has been used to treat a wide range of organic compounds including benzene, toluene, ethylbenzene, and xylene (BTEX), chlorinated solvents, pesticides, total petroleum hydrocarbons (TPHs), phenols, polyaromatic hydrocarbons (PAH), and nitroamines.

The vendor claims the following advantages for the technology:

- Treats organic and inorganic constituents.
- Short remediation time period (60 to 120 days).
- Installation in urban settings and under existing structures.
- Limited interference with on-site activities.
- Competitive costs for system installation and operation.
- No long-term operation and maintenance costs.
- Simultaneous treatment of soil and groundwater.

The waste stream must have a minimum moisture content of 6%. All information is from the vendor and has not been independently verified.

Technology Cost

No available information.

T0494

ManTech Environmental Corporation

CleanOX Process

Abstract

CleanOX® is an in situ technology for the treatment of contaminated groundwater and saturated soils. The process involves the injection of aqueous solutions of acetic acid, ferrous sulfate, and hydrogen peroxide into the zone of contamination. These chemicals react, producing hydroxyl radicals that oxidize hydrocarbons and other organic contaminants. According to the vendor, the process can be used to treat groundwater contaminated with chlorinated solvents, halocarbons, aromatic solvents, gasoline, fuel oil, coal tar, pesticides, and polychlorinated biphenyls (PCBs). CleanOX can be used to augment existing treatment technologies, such as pump-and-treat, air sparging, in-well stripping, or phytoremediation. CleanOX is patented and commercially available through ManTech Environmental Corporation.

According to the vendor, CleanOX has the following advantages:

- Process provides significant contaminant reductions in weeks to months.
- Mobile, in situ nature of the treatment system causes limited disruption to on-site operations.
- Process can be applied under buildings and within operational areas.
- CleanOX reagents are injected using standard 2-, 4-, and 6-inch monitoring wells, so capital costs are low.
- Process eliminates long-term operation and maintenance costs.

The CleanOX process is limited in saturated matrices possessing very low permeabilities and high calcium carbonate levels, as well as in groundwater with high total organic carbon content. In addition, the presence of iron-metabolizing bacteria can reduce the effectiveness of the iron catalyst, resulting in operations and maintenance problems for the system.

Technology Cost

According to the vendor, the cost of groundwater treatment with the CleanOX process ranges from cents per gallon to approximately $1 per gallon. Cost varies based on individual site characteristics such as volume and depth of contamination, flow rate, porosity, permeability, chemistry, temperature, pH, and salinity (D15553N).

During 1995 and 1996, CleanOX was used to treat volatile organic compounds (VOCs) in groundwater at an active industrial facility in Clifton, New Jersey. The total cost of the demonstration was approximately $235,000. This figure included expenses associated with drilling, chemical application, sampling, testing, and engineering oversight (D18766A, p. 8).

In 1996, pilot- and full-scale applications of CleanOX were performed to treat VOCs in an 80-ft by 80-ft contaminant plume in Framingham, Massachusetts. The total cost of this demonstration was $45,000. This figure included the cost of chemicals, chemical application, and expertise required for treatment; however, the cost of monitoring wells was not included (D18766A, p. 7).

Information Sources

D15553N, CleanOx Environmental Services, Inc., date unknown

D18766A, U.S. EPA, 1998

T0495

Maple Engineering Services, Inc.

Biopur

Abstract

Biopur® is a commercially available, ex situ, fixed-film bioreactor used for the treatment of groundwater and/or soil vapor contaminated with organic compounds.

The reactor is an aerobic, plug flow, packed-bed biofilm reactor. Reticulated polyurethane (PUR), a foam with large surface area, is used as the substrate for microorganisms. The substantial area available on the PUR for contact results in a high biomass concentration and thus high reaction rates at short retention times. Biopur can be used in conjunction with soil vapor extraction technology.

The technology is primarily used for the treatment of groundwater contaminated with aromatics such as benzene, ethylbenzene, toluene, and xylenes (BTEX) and volatile and nonvolatile organic hydrocarbons. Contaminants to be treated must be biodegradable; typically, biodegradation of chlorinated hydrocarbons is difficult. Iron concentrations above approximately 20 mg/liter can cause clogging of the filters. Systems in place for extended periods may require twice-yearly rinsing of the PUR to remove excess sludge.

The Biopur system requires little maintenance and has proven to be a cost-effective treatment alternative in Europe. The system is patented in the United States and in Europe, and is marketed in North America by Maple Engineering Services, Inc., Canada.

Technology Cost

Cost depends on flow rate through the reactor. In 1996, at slow flow rates [10 m^3/hr (m^3/hr)], the cost is about 0.50 deutsche marks per cubic meter, or $0.33/$m^3$. At a flow rate of 40 m^3/hr, the cost is about 0.35 deutsche marks, or $0.23/$m^3$ (D13549J, p. 5).

Cost of treatment was estimated in 1992 to be 0.50 francs ($0.40/$m^3$) per cubic meter of water and 1.00 to 5.00 francs ($.79 to $3.95) per cubic meter of vapor (D13104U, p. 70).

All conversions to dollars were made in November 1996.

Information Sources

D13549J, DOE, June 1996
D13104U, Oosting et al., 1992

T0496

MARCOR Environmental, Inc.

Advanced Chemical Treatment (ACT)

Abstract
MARCOR Environmental, Inc.'s, Advanced Chemical Treatment (ACT) is a chemical fixation method for the treatment of contaminated soils, sediments, and sludges. The vendor claims that by mixing contaminated materials with ACT reagents, the contaminants are oxidized, catalyzed, and mineralized. Target contaminants may include coal tar wastes; polycyclic aromatic hydrocarbons (PAHs); benzene, toluene, ethylbenzene, and xylenes (BTEX); chromium; copper; and lead.

According to the vendor, ACT has the following advantages:

- Takes days, rather than months or years, for contaminants to be treated.
- Results in long-term stability of treated media.
- Requires relatively small quantities of reagents compared to other methods (3 to 20% for ACT, compared to more than 30% for some methods).
- Can be used in situ or ex situ.

During bench-scale studies on ACT using sediments from the New Bedford Harbor Superfund Site, the Toxicity Characteristic Leaching Procedure (TCLP) concentrations of many contaminants increased or remained unchanged following treatment. Based on these results, researchers stated that solidification/stabilization methods such as ACT were not appropriate for the treatment of polychlorinated biphenyls (PCBs) or semivolatile organic compounds (SVOCs) at the site. The study also indicated that the compressive strength of ACT [45 to 80 pounds per square inch (psi)] was relatively low compared to other solidification/stabilization materials that were tested.

Technology Cost
Depending on the specific reagent needed to treat the target contaminant(s), ACT may be more expensive than other stabilization methods (D22737M, p. 6).

Information Source

D22737M, MARCOR Environmental, Inc., undated

T0497

Massachusetts Institute of Technology

Tunable Hybrid Plasma

Abstract
The Massachusetts Institute of Technology (MIT) has developed the tunable hybrid plasma (THP) system for the treatment of volatile organic compounds (VOCs) in gaseous waste streams. The reactor uses an electron beam to generate a plasma. The electron density of the plasma can be adjusted. This allows for the chemical reaction rates to be controlled as well as the intensity

of the superimposed subbreakdown magnetic field. This combination of control characteristics has led to the technology being called a tunable plasma. THP technology has been evaluated in bench-scale tests, and a pilot-level field demonstration using a similar electron beam technology has taken place.

Researchers claim the following advantages of THP:

- Relatively low-cost destruction of wastes at varying concentrations.
- More than 99.9% destruction and removal efficiency (DRE) without the production of undesirable products of combustion.
- High contaminant throughput and versatility.
- Possibility of building very small systems for low flow rates with modular electron beam technology.
- Attractive environmental and public acceptability features.

Performance is limited by the specific contaminant treated, the input concentration of the contaminant, the desired DRE, and the moisture content [twice as much energy is required to treat a humid waste stream (relative humidity of 10%) than to treat a dry waste stream].

Technology Cost

In 1996, MIT released results of a commercial evaluation of THP technology. The report stated that treatment costs would, generally, be significantly lower than costs using granular activated carbon and would be competitive with costs for thermal incineration and catalytic oxidation. The evaluation stated that cost projections for THP technology were approximately $0.65 for treatment of trichloroethylene at an initial concentration of 200 parts per million (ppm) and a flow rate of 5000 ft^3/min. Costs increased to several dollars per pound for carbon tetrachloride and trichloroethane. Energy requirements depend on the compound to be treated. Some compounds, such as Freon 113, may be impractical to treat cost-effectively because of the extremely high energy requirements per molecule (D13579P, p. 16). Researchers have stated that 100-kW level electron beam units cost approximately $5/W (D13894X, pp. 1–2). A comparison of THP to granular activated carbon, thermal incineration, and catalytic oxidation for four targeted contaminants at various flow rates is given in Table 1.

Information Sources

D13579P, Hadidi et al., 1996

D13894X, Truex et al., 1993

TABLE 1 Estimated Treatment Costs in Dollars per Pound for Trichloroethylene (TCE), Trichloroethane (TCA), and Carbon Tetrachloride (CCL_4) Using Tunable Hybrid Plasma, Thermal Incineration, Catalytic Oxidation, and Granular Activated Carbon[a]

	TCE		TCA		CCL_4	
Flow rate (in ft^3/min)	1000	5000	1000	5000	1000	5000
Tunable hybrid plasma	1.13	0.65	7.54	4.61	3.60	2.62
Thermal incineration	4.85	2.26	4.78	2.22	4.18	1.96
Catalytic oxidation	4.23	2.00	4.17	1.97	3.86	1.75
Granular activated carbon	21.52	21.52	21.2	21.2	24.79	24.79

Source: Adapted from D13579P.

[a] Assumed initial contaminant concentration 200 ppm, target destruction and removal efficiency (DRE) of 95%.

T0498

Matrix Photocatalytic, Inc.

TiO_2 Photocatalytic Treatment System

Abstract

The Matrix TiO_2 photocatalytic treatment system is a technology that destroys dissolved organic contaminants in water in a continuous-flow process at ambient temperature. The technology uses ultraviolet (UV) light and a titanium dioxide (TiO_2) semiconductor catalyst to break hydroxide ions (OH^-) and water (H_2O) into hydroxyl radicals ($OH^\bullet$). The radicals oxidize the organic contaminants to form carbon dioxide, water, and halide ions (if the contaminant was halogenated).

This technology is applicable to the treatment of industrial wastewater and contaminated groundwater. The same technology can also be used to effectively destroy airborne contaminants in the off-gases from industrial processes, air strippers, or soil vapor extraction operations.

This technology has been used several times in the field and is currently commercially available from Matrix Photocatalytic, Inc.

When insufficient amounts of hydroxyl radicals are available, incomplete degradation of contaminants may occur. Metals or solids in the influent may reduce process efficiency by costing or scaling the UV light source.

Technology Cost

During a field demonstration for the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration program, a Matrix TiO_2 photocatalytic treatment system was used to treat 11,000 liters of groundwater contaminated with benzene, toluene, xylenes, trichloroethene (TCE), tetrachloroethene (PCE), cis-1,2-dichloroethene (DCE), and 1,1-DCE. The estimated remediation cost for the system is approximately \$18/m^3. Of this cost, the direct treatment cost for the Matrix system was about \$7.60/m^3. These estimates are based on a 2-week demonstration that was not designed to evaluate process efficiency over time (D19079Y, p. 3–6; D14855U, p. 1).

Some generalizations can be made about this class of photocatalytic oxidation technologies. Because of the systems' unattended operation and readily available parts, operation and maintenance costs for these technologies are very low. In one extended field application, direct operating costs were \$1 to \$2 per 1000 gal of water treated (D108214, p. 311).

According to a 1995 EPA statement, capital costs for photocatalytic oxidation are very competitive with ultraviolet/hydrogen peroxide technologies, while operating costs are usually one-fifth to one-third less (D108214, p. 311). For treatment of contaminated airstreams, systems with capacities up to 1000 ft^3/min can be cost competitive with thermal oxidation systems (D106467, p. 313).

Matrix Photocatalytic, Inc., can conduct treatability tests for \$1500 if the waste sample is sent to them or for \$1750, plus travel and lodging expenses, for the tests conducted on-site.

Information Sources

D106467, U.S. EPA, 1995

D108214, U.S. EPA, 1995

D14855U, Matrix Photocatalytic, Inc., 1995

D19079Y, U.S. EPA, 1998

T0499

Maxymillian Technologies, Inc.

Indirect Desorption System (IDS)

Abstract
Maxymillian Technologies Inc.'s (MT's), indirect desorption system (IDS) is an indirectly heated thermal desorption technology for the ex situ treatment of soils containing semivolatile organic compounds (SVOCs), volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), and pesticides. Heating the soil causes organic contaminants to volatilize. Process off-gases are removed and condensed. The remediated soil is then returned to the site. A proprietary steam process enhances desorption efficiency. The technology is commercially available.

According to the vendor, IDS has the following advantages:

- The small space requirements and ease of transport allow for rapid mobilization.
- The system has throughputs of 10 to 20 tons per hour
- The system has a proven record of contaminant removal.
- As a closed-loop system, the system generates few waste products.

This technology is designed to treat waste material with a moisture content of up to 20%. Waste streams with higher moisture contents can be effectively desorbed at lower throughputs and/or with additional materials handling prior to thermal treatment.

Technology Cost
According to the vendor, the price range for IDS is $70 to $150 (1996 dollars) per ton of waste material. This estimate does not include all of the indirect costs associated with treatment such as excavation, permits, and treatment of residuals (D14723J, p. 21).

Factors that have a significant effect on unit price include the following:

- Quantity of waste
- Waste handling/preprocessing
- Soil characteristics
- Target contaminant concentration
- Labor rates
- Utility/fuel rates (D14723J, p. 21)

At a site in Boston, IDS was used to treat several thousand tons of soil contaminated with PCBs and solvents. The vendor claims the use of IDS and a soil containment cap at the site saved the client more $6.5 million that would have been spent on haul and treat methods (D22630C, p. 1).

Information Sources

D14723J, VISITT Version 5.0, 1996
D22630C, Maxymillian Technologies, undated

T0500

Maxymillian Technologies, Inc.

Thermal Desorption System

Abstract
The Maxymillian Technologies, Inc. (formerly Clean Berkshires, Inc.), mobile thermal desorption system (TDS) uses rotary kiln technology to remove contaminants from excavated soils and sediments. Thermal desorption is a physical separation process designed to volatilize water

and contaminants out of the contaminated media. The TDS can remediate soils contaminated with volatile organic compounds (VOC), semivolatile organic compounds (SVOC), polynuclear aromatic compounds (PAH), coal tars, and cyanide-containing compounds. The TDS is fully transportable, requires a footprint of 100-by-140 ft (30-by-43 m) and can be set up on-site in 4 to 6 weeks. The system combines high throughput with the ability to remediate mixed consistency soil, including sands, silts, clays, and tars.

This technology is currently commercially available.

Contaminated feed materials must have a minimum solids content of 60% to facilitate materials handling operations. The vendor advises that the unit has a waste heat value upper limit of approximately 300 British thermal unit (Btu) per pound (Btu/lb). Waste blending or homogenization is recommended as a means to evenly distribute both moisture and Btu content.

Compounds containing sulfur and cyanide become a potential source of air pollution when treated with this system. A caustic scrubber may be required to capture the combustion products of these compounds if sulfur and cyanide levels are high enough to exceed health and safety or applicable air quality standards. Metals that are not particularly volatile are not likely to be treated effectively by the TDS. Plastic materials are not recommended for treatment since their decomposition products could cause plugging or foul surfaces.

Technology Cost

According to the U.S. Environmental Protection Agency's (EPA) Vendor Information System for Innovative Treatment Technologies (VISITT) database, the estimated price for treating waste using the thermal desorption system ranges from \$40 to \$300 per ton (\$45 to \$330 per metric ton) of waste treated (D188527, p. 4). The cost depends on the following factors: quantity of waste, materials handling/preprocessing, characteristics of the soil, contamination type and concentration, labor rates, and utility/fuel rates (D10503T, p. 7; D102874, p. 18). Additional fixed costs for mobilization, testing, permitting, etc. range form \$50,000 to \$400,000.

For ex situ thermal desorption in general, \$15 to \$30 per ton (\$20 to \$35 per metric ton) is required for direct operating costs including utilities and repairs. Unit transportation and setup costs typically range from \$3 to \$5 per ton (\$3.30 to \$5.50 per metric ton). Excavation of contaminated soils and replacement of treated soils costs about \$5 to \$10 per ton (\$6 to \$11 per metric ton) (D18527, p. 4)

Information Sources

D10503T, U.S. EPA, 1994

D102874, VISITT database, 1995

D188527, FRTR, undated web site

T0501

MBI International

Anaerobic PCB Dechlorinating Granular Consortia

Abstract

The MBI anaerobic polychlorinated biphenyl (PCB) dechlorinating granular consortia technology is an in situ bioremediation technology that uses anaerobic microbial consortia in granular form to remediate PCBs in contaminated soils and sediments.

According to the vendor, advantages of this technology include the following:

- Provides substantial enhancement of rate and extent of dechlorination.
- Produces maximization of desired and selective metabolic performances.

- Requires no dredging and incineration.
- Is environmentally benign.

MBI's dechlorinating granules may be affected by extremely high levels of heavy metals or secondary organic pollutants, but they are not affected when concentrations of these contaminants are lower. Bioavailability of PCBs in contaminated sediments that are high in organic matter such as oil and grease may slow the dechlorination rate, causing longer reaction times for complete dechlorination of the PCBs.

Technology Cost
According to the vendor, this technology is estimated to cost less than $100 per ton of soil or sediment (D15094H). The cost for this technology can be much lower than other technologies because it does not require costly dredging of the contaminated sediments followed by secondary treatment and disposal or delivering oxygen to the sediments (D102841, p. 2).

Information Sources

D15094H, vendor literature
D102841, VISITT Version 4.0, 1995

T0502

McLaren/Hart Environmental Engineering Corporation

IRHV-200, IRV-150, and IRV-100 Thermal Desorption Systems

Abstract
The McLaren/Hart Environmental Engineering Corporation's (McLaren/Hart's) IRV-100 is a mobile, ex situ, low-temperature thermal desorption unit. The IRV-100 treats volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) in contaminated soil by using an infrared heating carriage. The IRV-150 and the IRHV-200 are enhanced versions of the IRV-100. The major enhancement is that both the IRV-150 and IRHV-200 operate under increased vacuum pressure.

According to the vendor, this technology is currently commercially available. The McLaren/Hart office in Charlotte, North Carolina, has a Toxic Substances Control Act (TSCA) Research and Development Permit for use of this technology.

The increased vacuum pressure of the IRHV-200 offers the following benefits:

- The amount of energy required to desorb target contaminants is significantly reduced when compared to the energy needed to remove these contaminants at atmospheric pressure.
- The low operating temperatures of the system significantly reduce the potential of forming thermal degradation products such as dioxins or furans. The contaminants essentially undergo a phase change from the liquid phase to a vapor stage and then return to the liquid phase. The chemical structure of the contaminants does not change.
- The atmosphere within the treatment chamber is essentially anaerobic. In the relative absence of oxygen and low operating temperature, the potential for formation of dioxins and furans during thermal desorption is essentially eliminated.

For the IRV-100, IRV-150, and the IRHV-200, waste material with moisture content of greater than 20% may slow run times by as much as 30 min to 1 h.

TABLE 1 Total Costs of the Full-Scale Remediation at the Farmer's Cooperative Exchange Superfund Site in Washington, North Carolina, 1995–1996

Cost Element	Cost (1996 $)
Capital Costs	
Mobilization/demobilization	
Mobilization of equipment	65,000
Site closure and demobilization	20,000
Site work/preparation	
Site preparation (permits not required)	15,000
Equipment and appurtenances	
Equipment modifications/rentals	907,200
Startup and Testing	
Performance evaluation	30,000
Subtotal	1,037,000
Operation and Maintenance	
Direct labor	
Labor	453,000
Subcontractors	75,600
Direct materials	
Utilities	150,000
Health and Safety	
Miscellaneous and health and safety	71,000
Analytical (related to technology performance not compliance monitoring)	
Treatment verification	40,000
Subtotal	789,600
Disposal of Residuals	
Waste disposal	18,000
Overall Project	
Total project cost	1,844,6000

Source: From D20081X.

Technology Cost

The cost for these technologies (IRHV-200, IRV-150, and IRV-100) is between $50 and $150 (1996 dollars) per ton of waste material treated. These price estimates do not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals.

Factors that have a significant effect on unit price include the following:

- Target contaminant concentration
- Initial contaminant concentration
- Moisture content of soil
- Quantity of waste
- Characteristics of soil (D14567P, p. 24; D14568Q, p. 34)

The total cost of the 1996 full-scale remediation of the Farmer's Cooperative Exchange Superfund Site in Washington, North Carolina, was $1,844,600. Based on the 13,591 yd^3 of contaminated soil treated, the unit cost was \$125/yd^3. Table 1 shows the breakdown of the total costs of the demonstration (D20081X, p. 67).

In 1993 through 1994, an IRV-100 thermal desorption unit was used to treat 13,986 yd^3 of soil contaminated with trichloroethene (TCE) at the U.S. Department of Defense's (DOD's) Letterkenny Army Depot Superfund Site in Chambersburg, Pennsylvania. The total project costs were \$5,402,801. This figure included \$4,647,632 for McLaren/Hart's application of the thermal treatment, \$192,827 for the DOD's design and project remediation, \$249,320 for the DOD's design contract, and \$312,320 for the DOD's construction contract management (D21039Z, p. 59).

At the DOE's Rocky Flats Environmental Technology Site in Golden, Colorado, an IRV-100 thermal desorption unit was used in 1996 to remediate 3796 yd^3 of contaminated soil and debris. The total cost of the full-scale deployment was \$1,934,203. The unit cost was \$350/yd^3 (D21039Z, p. 63).

Information Sources

D14567P, VISITT Version 5.0, 1996
D14568Q, VISITT Version 5.0, 1996
D20081X, Federal Remediation Technologies Roundtable, 1998
D21039Z, Federal Remediation Technologies Roundtable, 2000

T0503

Media and Process Technology, Inc.

Bioscrubber

Abstract

The Bioscrubber is an ex situ bioremediation technology for removing organic contaminants from gaseous streams.

The Bioscrubber technology is based on the use of granular activated carbon (GAC) in packed columns. The GAC acts as a filter on which microorganisms can attach and create an environment in which they degrade the organic contaminants in the gaseous waste streams passed through the filter.

Currently, the technology is not commercially available.

Technology Cost

No information available.

T0504

Medina Agricultural Products Company, Inc.

Medina Bioremediation Products

Abstract

Medina bioremediation products are commercially available compounds for the in situ or ex situ treatment of soil and water contaminated with petroleum hydrocarbons. Several products are available, and various combinations are used, based on specific site characteristics. Medina's products are applied directly to contaminated soils with conventional spray equipment. Soils are then tilled for thorough mixing. For the bioremediation of water, Medina bioremediation

TABLE 1 Costs of Medina Bioremediation Products (Supplied by the Vendor)

Product	Size	Cost
Microbial activator	5 gal (45 lb)	$42.50
	55 gal (510 lb)	$440.00
Bio-d nutrients	5 gal (50 lb)	$60.00
	55 gal (550 lb)	$643.50
Bio-s surfactant	5 gal (50 lb)	$60.00
	55 gal (550 lb)	$643.50
Degrading bacteria	1-lb bucket	$29.75
	25-lb bucket	$743.75

Source: From D16379V, p. 6.

products can supplement treatment at municipal wastewater treatment plants or in above-ground bioreactors.

Technology Cost

The costs of Medina bioremediation products are summarized in Table 1.

Information Source

D16379V, Medina Agricultural Products Co., Inc., date unknown

T0505

MeltTran, Inc.

The Ultimate Solution

Abstract

MeltTran, Inc. (MeltTran), has developed the Ultimate Solution™, an ex situ vitrification technology that uses a direct current (DC) arc system to treat hazardous wastes. The vendor claims that organic materials are destroyed by the technology and that inorganic materials are melted and cooled into a leach-resistant final waste form. RIMS were unable to obtain information from the vendor in regards to performance or commercial availability.

The vendor claims that the advantages of Ultimate Solution technology are cost effectiveness and technical efficiency. MeltTran claims the technology destroys organic compounds, while vitrifying inorganic materials into a glasslike material with a composition similar to the rock basalt. It claims that for some applications, a portion of the generated materials may have economic value as products. The vendor claims the technology can be applied to municipal waste, industrial hazardous waste, hospital wastes, and mixed waste.

Information in this summary is based on information from the vendor and has not been independently verified.

Technology Cost

According to the vendor, the Ultimate Solution can only operate economically in large treatment systems. The vendor supplied cost estimates for treating municipal solid waste, industrial hazardous waste, radioactive waste, and hospital solid waste at various treatment rates and with different numbers of shifts. The individual cost estimates are included in D15605I. The assumptions these estimates were based on were not made available to RIMS.

Information Source

D15605I, MeltTran, 1997, vendor web page

T0506

Membran Corporation

Membrane Gas Transfer

Abstract
Membran Corporation's membrane gas transfer system is a commercially available, patented technology for the ex situ or in situ treatment of groundwater contaminated with petroleum hydrocarbons and chlorinated aliphatic hydrocarbons. The technology may be used for on-site biological treatment of various wastewaters, including contaminated groundwater, and for in situ bioremediation of contaminated aquifers. The membrane gas transfer technology introduces gases to the water without forming bubbles, thus eliminating many of the problems associated with conventional gas transfer devices, such as poor gas transfer efficiencies, poor performance control, and atmospheric release of volatile organic compounds (VOCs).

The technology's ability to dissolve high concentrations of gaseous substrates without using bubbles has several operational and economic advantages: all of the gas applied to the transfer device is dissolved, eliminating gas wastage; since emissions are eliminated, there is no need for air pollution control equipment; combustible gases such as hydrogen and methane dissolve into water without a subsequent release of bubbles into confined spaces, allowing these gases to be safely utilized.

Oxygen, hydrogen, and/or methane can be dissolved to enhance the bioremediation process for a variety of contaminants. The technology can treat volatile and nonvolatile organic compounds and various halogenated aliphatic hydrocarbons, depending on the gas dissolved. To prevent fouling by oil, grease, or surfactants, the membranes may be covered with a thin, nonporous permeable coating. Acid rinses may be necessary to remove buildup in iron-rich water.

Technology Cost
A site with groundwater contaminated with benzene had an existing air stripper that was exceeding the regulatory limits for benzene emissions. An additional component would have to be added to the air stripper to treat the emissions. Cost comparisons were made for three alternatives: a granular activated carbon (GAC) filter, a 2000-gal (7571-liter) sparged-air bioreactor constructed from existing tanks on site, and a bioreactor with membrane-dissolution modules as the oxygen source in an effluent recycle loop.

Assuming benzene was the sole electron donor, a model predicted that the sparged-air bioreactor would still have benzene emissions above the regulatory limit, and would therefore require a GAC filter. Models predicted that the emission-free bioreactor that employed the membrane oxygen dissolution modules would be able to reduce the benzene concentration to within regulatory limits. The cost comparisons of the three alternatives are presented in Table 1. These figures assume that electricity costs \$0.050/kWh, oxygen costs \$0.40/lb, and granular activated carbon (GAC) has a replacement cost of \$3.00/lb (D130563, pp. 59–61).

Oxygenation of an aquifer contaminated with polycyclic aromatic hydrocarbons using membrane gas transfer modules cost approximately \$2.75 per day in 1995 (D130585, p. 526).

TABLE 1 Comparison of Projected Capital Costs for Major Bioreactor Components and of Operating Costs for Three Treatment Alternatives for Benzene-Contaminated Water (Costs in U.S. Dollars, 1995)

Treatment Alternative	Capital Cost for Modifications	Operating Cost ($per day)
Existing air stripper		$4.50
5-hp blower GAC replacement		53.85
Totals		$58.35
Sparged-air bioreactor with air stripper	$1,500.00	$4.50
5-hp blower–bioreactor	2,500.00	9.30
Structured media		4.50
GAC replacement—bioreactor		20.60
5-hp blower–air stripper		
GAC replacement—stripper		
Totals	$4,000.00	$38.90
Emission-free bioreactor with air stripper	$500.00	$1.30
1.5-hp recycle pump	2,000.00	2.00
Oxygen cost	2,500.00	4.50
Membrane oxygen dissolution system		
Structured media		
5-hp blower–air stripper		
Totals	$5,000.00	$7.80

Source: From D130563, p. 60.

T0507

Membrane Technology and Research, Inc.

VaporSep Membrane Recovery System

Abstract
The VaporSep™ membrane recovery system uses synthetic polymer membranes to remove organic vapors from contaminated airstreams. These membranes are much more permeable to heavy organic vapors than to light gases such as nitrogen, hydrogen, or methane. When a vacuum is applied to one side, the organic vapors pass through and are condensed for recovery.

VaporSep is designed to treat vapor streams that are too dilute for concentration methods, but too concentrated for carbon adsorption. The vendor offers single-stage membrane systems for treating concentrated, organic vapor streams [i.e., those containing more than 1000 parts per million (ppm) by volume]. A two-stage membrane system was developed for treating streams with concentrations of less than 100 ppm. VaporSep has been demonstrated in bench-, pilot-, and full-scale studies. The technology has been commercially available since 1990.

According to the vendor, some advantages of the VaporSep technology are that it:

- Is guaranteed.
- Is chemically resistant to many solvents.
- Has a long membrane life.
- Is applicable to a broad range of off-gas generating sources.
- Minimizes waste volume.
- Is suitable for remote sites.

Carbon adsorption with regeneration may be a better treatment option when the volatile organic compound (VOC) concentration is less than 100 ppm. High levels of very permeable gases, such as carbon dioxide, may reduce the system's efficiency.

Technology Cost

All of the available cost information for the VaporSep technology comes from industrial applications. These costs may not be representative of costs for the remediation of hazardous wastes.

Capital costs can vary between \$30,000 and \$300,000, depending on design of the system, its capacity, and the specific application (D12740C, p. 1). According to the vendor, the capital costs range from \$400 to \$1000 per standard cubic feet of influent gas per minute. The installed costs for a VaporSep designed to purify natural gas were estimated at \$1.1 million. The vendor estimates that operating costs range from \$0.50 to \$1.00 per 1000 standard cubic feet of influent gas per minute (D13497O, p. 11). The cost of the system increases with higher flow rates but is independent of the VOC concentration (D12736G, p. 4; D22749Q, p. 13).

In making polyvinyl chloride (PVC), much of the VOCs used in the process are wasted. Generally, the vent stream contains 50 to 75% of the VOCs at low concentrations (D12739J, p. 94). Using VaporSep membrane separation, 90 to 99% of the original waste stream can be directly recycled, and at a lower cost. Inlet concentrations range from 35 to 50% by volume and outlet concentrations range from 2 to 5% by volume. The first three units installed by Membrane Technology and Research (MTR) paid for themselves within the first year of operation. Capital costs and first-year savings are indicated in Table 1. These estimates are calculated in 1994 dollars. The figures were calculated based on 8000 hr of use per year and a cost of \$0.20/lb of recovered vinyl chloride monomer (D12739J, p. 94).

A VaporSep system was installed at a polyethylene plant to recover 290 lb of ethylene per hour (lb/hr) from a gas stream consisting of 18% hydrogen, 22% nitrogen, 30% methane, and 30% ethylene. The capital costs for the system were \$200,000. Based on an ethylene value of \$300 per ton, the plant would save \$370,000 per year using the VaporSep system to purify and recycle the ethylene (D205549, p. 5).

The capital costs for a VaporSep system installed at a plastics manufacturing plant were \$300,000. The waste stream contained 5 lb/hr of hydrogen, 172 lb/hr of nitrogen, 328 lb/hr of ethylene, 7 lb/hr of ethane, and 288 lb/hr of butene. The system recovered 290 lb/hr ethylene and 284 lb/hr of butene. Based on a value of \$300 per ton for each ethylene and butene, the plant saved an estimated \$700,000 per year by recycling the hydrocarbons (D205549, p. 6).

The gaseous waste stream at a plastics manufacturing plant consisted of 1620 lb/hr of nitrogen, 100 lb/hr of carbon dioxide and oxygen, 2370 lb/hr of iso-butane, and 10 lb/hr of water. A VaporSep system was installed at a cost of \$1.3 million to recover 2325 lb/hr of iso-butane. If the iso-butane is valued at \$200 per ton, the plant saved an estimated \$2 million per year (D205549, p. 8).

A VaporSep system recovered approximately 91% of the hydrocarbons from a waste stream of hydrogen, nitrogen, propane, propylene, and water. The capital costs for the system were \$2.4 million. By recycling the hydrocarbons and nitrate (permeate and filtrate), the system saved \$2.3 million per year (D205549, p. 9).

TABLE 1 Vinyl Chloride Monomer Recovery Costs

Plant	1	2	3
Capital costs (1994 dollars)	\$150,000	\$65,000	\$50,000
First-year savings (1994 dollars)	\$450,000	\$158,000	\$66,000
Vinyl chloride monomer concentration (volume)	35%	50%	45%

Source: Adapted from D12739J.

According to the vendor, savings for some industries will be even more dramatic. For example, a typical polyolefin producer will vent 1000 to 2000 lb/hr of recoverable nitrogen and 500 to 1000 lb/hr of recoverable monomer and processing solvent. At current prices that amounts to roughly $1 million per year that could be saved (D12734E, p. 1). In the manufacture of pharmaceuticals, approximately 22 of solvents (over 50% for methylene chloride) are currently lost to emissions. According to the vendor, a typical VaporSep system will pay for itself within a period of 6 to 12 months by recovering valuable hydrocarbons and purifying inert gases (D18997N, p. 3).

Information Sources

D12734E, Baker and Jacobs, 1996

D12736G, Simmons et al., 1994

D12739J, Simmons et al., 1994

D12740C, National Renewable Energy Laboratory, web page

D13497O, Membrane Technology and Research, Inc., 1990

D18997N, Membrane Technology and Research, Inc., undated

D205549, Jacobs et al., 1999

D22749Q, Lokhandwala et al., undated

T0508

Mercury Recovery Services, Inc.

Mercury Removal/Recovery Process

Abstract

Mercury Recovery Services, Inc. (MRS), has developed the Mercury Removal/Recovery Process (MRRP) to treat media contaminated with mercury. The ex situ process uses medium-temperature thermal desorption to remove the mercury from contaminated wastes. Process wastes are heated in a two-step process to recover metallic mercury in a 99% pure form. MRS claims MRRP can be applied to soils, activated carbon, mixed waste, catalysts, electrical equipment, batteries, lamps, fluorescent bulbs, mercurous and mercuric compounds, mercury-contaminated waste liquids, and debris.

MRRP technology is patented (U.S. Patent 5,300,137) and commercially available.

The vendor claims the following advantages to MRRP technology:

- Can reduce mercury levels to less than 1 part per million (ppm) in treated soil regardless of initial mercury concentration.
- Produces a 99%-pure metallic mercury product suitable for refining.
- Can recovery mercury contaminants in chloride, sulfide, or oxide forms while preventing the release of sulfur or chlorine into the process exhaust.
- Can treat materials with high initial-moisture content.
- Gaseous effluent meets applicable clean air standards.

The vendor states that MRRP may not be cost effective for contaminated water or wastewater as a primary treatment system but could recover mercury from carbon systems used to treat these waste streams. According to the Gas Technology Institute, the mobilization and demobilization of mobile thermal treatment systems can be costly and time consuming. These technologies are often energy intensive.

TABLE 1 Operating Cost[a] Estimate for a 110-Ton/Day Mercury Removal/Recovery Process Mixed-Waste Facility

Cost Category	Dollars/Ton	Dollars/Metric Ton
Supervision	3	3.3
Operating labor	14	15.4
Electric power consumption	48	52.9
Activated carbon adsorption	9	9.9
Chemical additive consumption	2	2.2
Laboratory analysis	15	16.5
Nonelectric utilities	1	1.1
Maintenance parts/consumables	12	13.2
Maintenance labor	2	2.2
Personnel protection consumables	1	1.1
Total	107	117.9

Source: Adapted from D126147.
[a] Operating costs do not include excavation, transportation to and from recycling facility, and management of processed wastes/soils. No value is placed on recovered mercury.

Technology Cost
In 1996, Weyand and Koshinski estimated the costs of an MRRP facility that treated 110 tons of mercury-contaminated wastes per day and 40,000 tons of waste per year. The estimated capital costs were $10.5 million, and the direct operating cost were $107 per ton of soil treated (D126147, p. 6). Operating cost data is summarized in Table 1.

In a 1995 estimate published in the VISITT database, total MRRP costs for waste treatment ranged from $650 to $1000 per ton. The primary factors impacting treatment costs were the quantity of the waste and the moisture content of the waste. Treatment costs were also impacted by utility and labor costs. Other factors that have an effect on treatment costs include (in decreasing order of importance) site preparation and pretreatment costs, characteristics of the soil and residual wastes, costs associated with removal of debris from the soil, and the initial and target contaminant concentrations (D102852, p. 34).

MRRP technology will have higher operating costs than some competing technologies due to its lower throughput. The vendor states that this increased cost is offset by the fact that no additional waste streams are produced and the recovered mercury has economic value (D175911, p. 7).

Information Sources

D102852, VISITT 4.0, 1995

D126147, Weyand et al., 1996

D175911, Wastewater Technology, 1998

T0509

Metal-Based Permeable Reactive Barriers — General

Abstract
Metal-based permeable reactive barriers (metal-based PRBs) are an emerging class of in situ technologies for the treatment of groundwater contaminated with volatile organic compounds

(VOCs), uranium, and heavy metals. There has been extensive research on various materials for use in PRBs. Metal-based PRBs are common because the reactive material is commercially available at low costs and has been effective on a variety of contaminants. Metal-based PRBs act as selective filters to contaminants and are being developed in response to the need for effective, low-cost technologies to remediate contaminated subsurface environments. The barriers are permeable to water and nontargeted groundwater constituents and impermeable or destructive to the target contaminant(s).

Metal-based PRBs involve the introduction of metals, usually zero-valent iron, but sometimes metal wool, palladium, or other metals to chemically react with the target contaminant(s), causing chemical adsorption with and/or destruction of the contaminants. These materials are typically permeable to water and thus avoid the groundwater management and flow problems associated with impermeable barriers.

According to the U.S. Navy, PRBs have the following advantages:

- Passive, in situ treatment system for contaminated groundwater.
- Sites can remain productive during remediation efforts.
- Treatment conducted at roughly one fourth the cost of a pump-and-treat system.
- low, long-term operation and maintenance costs.
- versatile system can treat many different types of contaminants.

Site-specific factors can limit the effectiveness of metal-based PRB performance. In high pH environments, nitrate can form ammonium when passing through a PRB. In those same high pH environments, bicarbonate in groundwater can precipitate as carbonate, forming deposits that can reduce the permeability of the PRB.

PRBs have the following limitations:

- Clogging of the barrier due to biological or chemical precipitates may require maintenance.
- Complications during installation caused by above-ground structures and underground utilities.
- Geologic limitations such as the need for an aquiclude and the increasing costs as contaminant depth increases.
- Increased short-term capital costs for construction and installation when compared with pump-and-treat.

Technology Cost

According to one vendor, total capital costs for a PRB containing granular iron were approximately \$720,000 in 1994. The net present value (NPV) of the system over a 30-year lifetime is estimated to be \$4.4 million. This represents a \$3.4 million savings over the estimated NPV for the former pump-and-treat system for the same length of time. Both estimates of NVP include capital as well as operations and maintenance (O & M) costs (D12778Q, p. 91; D12777P).

For PRBs using zero-valent iron, the cost of the reactive media can be estimated based on a density of about 2.83 kg of media per meter and a cost of approximately \$440 to \$500 per ton. An installation cost between \$2500 and \$8000 per liter for each minute of treatment capacity is a rule-of-thumb for estimating capital cost. Because the elemental iron treatment wall is patented, a site licensing fee is often required. O & M costs are generally estimated to range from \$1.30 and \$5.20 per 1000 liters of treated water (D16068J). Costs for several metal-based PRB deployments are given in Table 1.

Information Sources

D12778Q, Focht et al., Remediation/Summer 1996

D12777P, Vogan et al., date unknown

TABLE 1 Metal-Based Permeable Barrier Field Deployments

Site (P = pilot)	Contaminants[a]	Date	Cost
Elizabeth City, NC, electroplating	Hexavalent chromium (Cr), TCE[2]	1996	$500,000 for design and installation
Moffett Federal Airfield, Mountainview, CA, solvents (P)	TCE, DCE, PCE	1996	$100,000 for design, $365,000 for installation
Caldwell Trucking, NJ, industrial waste	TCE	1998	$1,120,000 for design and installation of two walls
Rheine, Westphalia, Germany, dry cleaner	PCE, 1,2-DCE	1998	$30,000 for design, $93,000 for installation
Federal Highway Administration Facility, Lakewood, CO	TCA, TCE, 1,1-DCE, cDCE	1996	$1,000,000 for design and installation
Fairfield, NJ, manufacturing site	1,1,1-TCA, PCE; TCE, DNAPL	1998	$150,000 for design, $725,000 for installation
Coffeyville, KS, industrial site	TCA, 1,1,1-TCA	1996	$400,000 for installation
Central New York, industrial site	TCE, vinyl chloride	1997	$797,000 for installation
Belfast, Northern Ireland, industrial site	TCE, 1,2-DCE	1995	$375,000 for installation
Watervliet Arsenal, Watervliet, NY, chemical storage (P)	PCE, TCE, cDCE, vinyl chloride	1998	$113,000 for design, $257,000 for installation
Portsmouth Gaseous Diffusion Plant, Piketon, OH, wastewater (P)	TCE	1996	$4,000,000 for installation

Source: Adapted from D20628A, D20629B, D203736, D203703, D203689, D20369A, D203747, D203725, D203714, D206246, D206111, D206304, D206224.

[a] Abbreviations: TCE, trichloroethylene; DCE, dichloroethylene; PCE, perchloroethylene; TCA, trichloroethane; cDCE, cis-dichloroethylene; DNAPL, dense, non-aqueous-phase liquid.

D206246, RTDF, undated web page
D20369A, RTDF, undated web page
D203689, RTDF, undated web page
D203703, RTDF, undated web page
D20628A, RTDF, undated web page
D20629B, RTDF, undated web page
D206224, RTDF, undated web page
D206304, RTDF, undated web page
D206111, RTDF, undated web page
D203714, RTDF, undated web page
D203725, RTDF, undated web page

D203747, RTDF, undated web page
D203736, RTDF, undated web page

T0510

Metals Recovery, Inc.

Metals Leaching

Abstract
The metals leaching technology offered by Metals Recovery, Inc., involves soil washing for the leaching of hazardous metals from soils with a nonacidic, proprietary solution. After mixing the proprietary leaching solution with the soil, solids are separated from the washing solution. Metals are then precipitated from the solution. The solution is regenerated and reused in the leaching process. The metals are concentrated and sold to a smelter. The soil is backfilled on site. The chemicals employed in the washing process are nonhazardous and nonvolatile. This technology does not require the input of thermal energy. The processing time depends on the soil type, the metals present, and their concentrations. Currently, it is being used commercially to extract metals from filter cakes from industrial facilities such as plating factories; however, pilot-scale remediation tests have been performed.

This technology works most effectively on oxidized metals. It does not work effectively on elemental metals. The technology will be effective when hydrocarbon concentrations are below 1000 parts per million (ppm). It may be used as a second step in combination with hydrocarbon remediation. The pH should be close to neutral and can be adjusted before remediation. All information is from the vendor and has not been independently verified.

Technology Cost
According to the vendor, the average cost of this technology ranges from \$100 to \$170 per ton (D10157V, pp. 1 and 14).

Information Source

D10157V, VISITT 4.0, 1995

T0511

Metals Removal Via Peat — General

Abstract
Metals removal via peat is an in situ, passive treatment technology being developed to treat groundwater contaminated with heavy metals and radionuclides. Bench-scale tests indicate that peat may be an inexpensive and effective material for trapping metals.

Peat materials have been used as sorbents in treating household waste waters, providing excellent performance in removing biological oxygen demand (BOD), suspended solids and coliform from septic tank effluent. Increasingly, organic sorbents such as peat moss are used for treating industrial wastes. Recently, research has been conducted on the use of peat as a sorption media for heavy metals by the U.S. Department of Energy (DOE) at Oak Ridge National Laboratory (ORNL), and by the Universities of South Carolina and Missouri-Kansas City.

Technology Cost
No available information.

T0512

Metcalf & Eddy

Aqua-Sparg

Abstract
Aqua-Sparg is an in situ technology for the treatment of groundwater contaminated with volatile organic compounds (VOCs). The technology introduces pressurized air below the groundwater table to volatilize contaminants.

All information was provided by the vendor and has not been independently verified. This technology is no longer commercially available.

Technology Cost
No available information.

T0513

Metcalf & Eddy

TERRA-PURE System

Abstract
TERRA-PURE is an in situ technology that utilizes a flushing system for extraction of contaminants from soil. According to the vendor, it is applicable to organic and inorganic contaminants present at relatively high concentrations and to non-aqueous-phase liquids.

This technology is no longer commercially available.

Technology Cost
No available information.

T0514

Metcalf & Eddy, Inc.

GEMEP

Abstract
GEMEP^{SM} is a patented technology for the on-site treatment of various solid matrices impacted with mercury. GEMEP is an ex situ process based on the selective oxidation and solubilization of mercury into an aqueous solution, followed by the physical separation of the mercury-laden solvent from the solid matrix, and the subsequent treatment of the solvent to recover the mercury and recycle the solvent.

GEMEP is currently commercially available. The first full-scale commercial application of the technology is scheduled for early summer of 1997 on a Region 2 Superfund site.

According to the vendor, GEMEP has the following advantages:

- GEMEP selectively oxidizes mercury, leaving indigenous inorganics (i.e., iron, manganese, calcium) in the solid phase. Strong acid leaching processes solubilize significant quantities of indigenous material.
- GEMEP is applicable to virtually all chemical forms of mercury, including those with very low vapor pressures, such as mercury oxide or sulfide. These high boiling compounds are problematic for thermal desorption.
- GEMEP operates at low temperature and pressure and uses a relatively mild chemical oxidant, resulting in a process that is inherently safer than strong acid leaching or thermal desorption systems.
- GEMEP uses conventional chemical processing equipment and can be easily and economically scaled up or down.

Waste streams with high organic content can result in excessive iodine losses, which can adversely impact the cost of this technology.

Technology Cost

The cost for this technology is $125 to $400 (1996 dollars) per ton of waste material treated. This estimate does not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals. Factors that have a significant effect upon unit price include the following:

- Quantity of waste
- Characteristics of soil
- Target contaminant concentration
- Initial contaminant concentration (D15317D, p. 8)

Information Sources

D15317D, VISITT Version 5.0, 1996
D15314A, Metcalf & Eddy, Inc., vendor literature

T0515

Metcalf & Eddy, Inc.

HYDRO-SEP Soil Washing Technology

Abstract

The Metcalf & Eddy HYDRO-SEP^{SM} soil washing system is an ex situ, water-based technology that separates contaminants from soil matrices. The HYDRO-SEP modular system uses screening and hydraulic classification processes to separate uncontaminated soil particles from a contaminated mixture.

According to the vendor, the HYDRO-SEP soil washing technology, when used with two other Metcalf & Eddy technologies [METAL-SEP (extracts metals) and ORGANO-SEP (extracts organics)] has successfully treated the following metallic and organic compounds: arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, selenium, zinc, pesticides, chlorinated aromatics, dioxin, dibenzofurans, polynuclear aromatic compounds (PAHs), and phthalates.

TABLE 1 Full-Scale Project Cost Analysis

Task	Quantity (000s)	Units	Total Cost: Soil Washing	Total Cost: Stabilization/ Nonhazardous Disposal	Total Cost: Hazardous Disposal
Excavation	30	Cubic yards	\$150,000	\$150,000	\$150,000
Site preparation	LS[a]	—	50,000	50,000	50,000
Soil treatment	36	Tons	4,183,500	1,920,000	0
Disposal	8.3	Tons	1,910,000	—	—
	43.1	Tons	—	5,734,000	—
	36	Tons	—	—	9,000,000
Restoration	20	Cubic yards	105,000	300,000	300,000
Post-excavation sampling	LS	—	84,500	84,500	84,500
Project management	LS	—	972,450	1,235,775	958,450
Contingency	LS	—	648,300	823,850	958,450
TOTAL			\$8,103,750	\$10,298,125	\$11,501,400

Source: From D14705H, p. 2.
[a]LS = land specific.

The vendor asserts that the technology is:

- Economical
- Modularly designed making it versatile to use
- Transportable and easily adaptable to different site conditions
- Environmentally benign (most material is either treated on site, recycled, or reused)

Technology Cost

According to the vendor, soil washing is more cost effective for full-scale cleanups than either stabilization or disposal. Table 1 shows a full-scale project cost analysis comparing costs for soil washing, stabilization, and disposal methods (D14705H, p. 2).

The cost for using the Metcalf & Eddy HYDRO-SEP soil washing technology to remediate 500 yd^3 of soil in a pilot study at Lake Success (Bridgeport, CT) was \$1 million. See Case Study 1 for additional information (D14707J, p. 2).

Information Sources

D14705H, Warminsky and Shekher, date unknown

D14707J, Metcalf & Eddy, Inc., date unknown

T0516

Metcalf & Eddy, Inc.

ORG-X

Abstract

ORG-X is an ex situ solvent extraction technology used to separate organic compounds from contaminated sediment. This technology was originally designed for use at manufactured gas

plants, but it is suggested that it may also be applied at a wide range of sites for extraction of oils, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), dioxins, and pesticides. The vendor uses ORG-X both as a stand-alone technology and in combination with Hydro-SEP, a sediment washing technology, and SOLFIX, a stabilization technology. Metcalf & Eddy refers to this combined technology train as its integrated sediment decontamination system (ISDS).

The vendor claims the following benefits for the technology:

- High removal performance
- Applicability to most organics and soil types
- Biodegradable solvent formulations
- Fully operational mobile, stand-alone processing plants

All information is from the vendor and has not been independently verified. This technology is no longer commercially available.

Technology Cost
According to the vendor, ORG-X costs for treating contaminated soil range from $200 per ton for treatment of 2000 tons to less than $100 per ton for treatment of 100,000 tons (D16138G, p. 4).

Information Source

D16138G, Metcalf & Eddy, date unknown

T0517

Metcalf & Eddy, Inc.

SOLFIX

Abstract
SOLFIX is an ex situ stabilization technology that treats heavy metals by reacting contaminated soils and sediments with cement, pozzolanic materials, and other additives to chemically immobilize contaminants into an insoluble form. SOLFIX can be used either as a stand-alone technology or it can be incorporated with Hydro-SEP (a sediment washing technology) and ORG-X (a solvent extraction technology) into a three-step remediation process termed integrated sediment decontamination system (ISDS).

All information is from the vendor and has not been independently verified. Commercial availability in the United States remains uncertain according to Metcalf & Eddy.

Technology Cost
No available information.

T0518

Met-Chem

Metal Kleen A

Abstract
Met-Chem (formerly Metal Kleen, L.L.C.) is the U.S. licensee of Metal Kleen A (MCA), a patented chemical treatment for removal of heavy metals from wastewater, flue gas, soils, and

sludges. MCA is an inorganic product with a polysulfurous base. Treatments allow sulfur to react with metallic ions in solution, forming insoluble metal sulfides. Treatment normally requires a weakly acidic solution (pH between 3.0 and 4.5). The technology has been used commercially in Germany since the late 1980s and has been commercially available in the United States and Canada since 1995. All commercial applications of MCA have been for ex situ treatment, but the vendor claims in situ techniques for MCA have been tested in the laboratory, but no commercial applications have been attempted.

Met-Chem claims the following advantages of MCA:

- MCA often costs less than competing treatment technologies.
- MCA products are in a liquid form and minimize handling problems.
- Significant volume reductions are possible using MCA technology.
- Treated materials pass toxicity characteristic leaching procedure (TCLP) criteria.
- MCA is nonflammable and poses no fire hazard.

According to the vendor, MCA treatment may produce a fine precipitate that usually requires flocculation. If MCA is used in waste streams with a pH lower the 3.0, a hydrogen sulfide odor may be produced.

Technology Cost

According to the information supplied by the vendor, MCA is competitively priced with other specialty precipitation chemicals. The vendor claims that since low dosage rates may be achievable with MCA treatment, significant cost reduction can be achieved over other chemical technologies, and chemical precipitation is significantly less costly than demineralization, ultrafiltration, or reverse osmosis. The vendor also claims that significant volume reductions are possible with MCA treatment of sludge, and that minimum equipment additions and modifications are necessary to use MCA in existing wastewater treatment systems (D13628H, pp. 2–4, 4–3). In water treatment applications, the vendor claims MCA has higher unit costs than dithiocarbamates but often lower operating costs because of higher efficiency and less sludge generation (D13628H, p. 4–6).

In applications using MCA for mercury gas treatment, the vendor estimated in 1996 that operating costs would be $0.015 per ton of waste treated, product costs would be $0.13 per ton, and operations and maintenance costs would be $0.085 per ton, for a cost per ton of waste of $0.23. The vendor claims MCA is significantly cheaper than a competing technology, activated carbon removal. This estimate is based on a mass-burn municipal waste facility generating 860,000 tons of waste per year with a mercury concentration of 300 $\mu g/m^3$ (D13628H, p. 3–13).

Information Source

D13628H, Metal Kleen, L.L.C., 1996

T0519

Met-Chem

Metal Kleen B

Abstract

Met-Chem (formerly Metal Kleen, L.L.C.) is the U.S. licensee of Metal Kleen B (MCB), a patented chemical treatment for removal of heavy metals from wastewater, flue gas, soils, and sludges. MCB is an inorganic multicomponent mixture of thio sulfur compounds. Treatments allow sulfur to react with metallic ions in solution, forming insoluble metal sulfides. Treatment normally can occur over the full range of process pH. The technology has been used commercially in Germany since the late 1980s and has been commercially available in the United States and Canada since 1995. MCB has proven effective in the removal of heavy metals from spent alkaline solutions generated in the nickel-cadmium battery industry. According to the vendor, all of the German nickel-cadmium battery manufacturers use MCB to treat caustic solutions that are then reused in the facility to neutralize acid wastewater.

Met-Chem claims the following advantages of MCB:

- MCB often costs less than competing treatment technologies.
- MCB is in a liquid form that minimizes handling problems.
- Significant volume reductions are possible using MCB technology.
- Can be used at any pH.
- Hydrogen sulfide emissions controlled below regulated limits.
- Treated materials pass toxicity characteristic leaching procedure (TCLP) criteria.
- MCA is nonflammable and poses no fire hazard.

According to the vendor, MCB treatment produces a fine precipitate that usually requires flocculation or filtration. For some applications, additives such as lime, hydrogen peroxide, polyelectrolyte, ferrous chloride, iron sulfate, or flocculants may be necessary to meet treatment objectives. MCB has an ammonia odor.

Technology Cost

According to the information supplied by the vendor, MCB is competitively priced with other specialty precipitation chemicals. The vendor claims that since low dosage rates may be achievable with MCB treatment, significant cost reduction can be achieved over other chemical technologies, and chemical precipitation is significantly less costly than demineralization, ultrafiltration, or reverse osmosis. The vendor also claims that significant volume reductions are possible with MCB treatment of sludge and that minimum equipment additions and modifications are necessary to use MCB in existing wastewater treatment systems. MCB applications can be designed to work with conventional water treatment equipment (D13628H, pp. 2–3, 2–6). In water treatment applications, the vendor claims MCB has higher unit costs than dithiocarbamates but often lower operating costs because of higher efficiency and less sludge generation (D13628H, p. 4–6).

Information Source

D13628H, Metal Kleen, L.L.C., 1996

T0520

Methanotrophic Biofilters — General

Abstract

Methanotrophic biofilters are a biological technology for remediation aqueous- and liquid-phase organic contaminants, particularly chlorinated organics. This technology utilizes a type of bacteria, known as a methanotroph, that consumes methane as a nutrient source.

Nonproprietary biofilters have been used successfully for more than 20 years. Proprietary designs are also available. Biofilters have been used extensively in Europe and Japan, and have been receiving attention in the United States as well. Biofilters are commercially available from a number of vendors.

A methanotrophic biofilter is a biofilter in which methanotrophs are present. In a biofilter, a gas- or aqueous-phase contaminant stream is passed through a media on which the bacteria are growing. The media can be of several different materials, including compost, peat, soil material, or granular activated carbon. Specific strains of bacteria may be introduced into the filter and optimal conditions provided to preferentially degrade specific compounds.

The following have been described as limitations of biofilters in general: rate of influent airflow is constrained by the size of the biofilter, fugitive fungi may be a problem, and low temperatures may slow or stop removal.

Technology Cost

Cost estimates range from \$5 to \$10/kg of contaminant (\$2.27 to \$4.54/lb) (D10940A, p. 207).

T0521

Met-Tech Inc.

Metal Separation by Liquid Ion Exchange

Abstract

The Met-Tech separation process is a liquid ion exchange process for the ex situ recovery, separation, and concentration of a wide range of heavy metals. The technology is commercially available and, according to the vendor, has been tested at the pilot scale. According to the vendor, future applications will be in soil remediation, acid mine drainage, and the recycling of spent nuclear waste.

All information was supplied by the vendor and was not independently verified.

Technology Cost

No available information.

T0522

Micro-Bac International, Inc.

M-1000 Series Bioremediation Products

Abstract

M-1000™ series bioremediation products are commercially available, specialized microorganisms used for the in situ treatment of soil or groundwater contaminated with various volatile and semivolatile organic compounds (VOCs and SVOCs) and other hazardous substances. The technology can also be used to treat contaminants ex situ, in either a biological reactor or biopile. M-1000 products can be used to augment existing mechanical cleanup technologies, such as pump and treat.

According to the vendor, M-1000 products can be used to degrade benzene, toluene, ethylbenzene, and xylenes (BTEX), polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and high-molecular-weight alkanes.

Certain types and levels of heavy metals can be detrimental to the biological process, as can some other microbial inhibitors such as pH, extreme temperature, lack of moisture, and lack of soil permeability/porosity.

Technology Cost
According to the vendor, the effective treatment of 20 m^3 of diesel-based drilling muds during a pilot-scale field demonstration in 1993–1994 cost an estimated \$35.00/yd^3 (D13880R).

M-1000H* microbes and nutrients were used to treat soil contaminated with fuel oil beneath a private residence in Massachusetts. According to the vendor, the total cost of the 8-month demonstration was less than \$25,000 (D20031N, p. 3).

During a full-scale remediation at a manufacturing company's service station in Pennsylvania, the Micro-Bac International, Inc., bioremediation process was used to treat 650 yd^3 of soil contaminated with No. 6 fuel oil. The vendor estimated that the in situ operation cost \$25.00/yd^3 (D10281Y, p. 8–11).

Approximately 6000 yd^3 of soil at a service station in southeastern Maine were contaminated with kerosene and BTEX. According to the vendor, the cost of the full-scale, in situ remediation was approximately \$40.00/yd^3 (D10281Y, p. 13–16).

Information Sources

D10281Y, VISITT 4.0, undated

D13880R, Micro-Bac International, Inc., 1994–1996

D20031N, Micro-Bac International, Inc., undated

T0523

Microbe Technology Corporation

Bac-Terra Remedial Technology

Abstract
Bac-Terra remedial technology is an in situ bioaugmentation technology. Bac-Terra includes natural organic matter with a blend of microbial consortia, including psychrophilic, mesophilic, thermophilic, and eurythmic bacteria cultures for use at temperatures ranging from 28 to 240°C. Bac-Terra is capable of working in both aerobic and anaerobic environments.

Bac-Terra was developed by FIFCO International 15 years ago and is currently marketed through the Weber Realty Services, Inc., of Jacksonville, Florida, for Microbe Technology Corporation.

Bac-Terra requires soil moisture greater than 20%. Covering the treated area with plastic to prevent evaporation may be sufficient to maintain soil moisture in some areas. All information is from the vendor and has not been independently verified.

Technology Cost
According to the vendor, the estimated price of this technology is \$20 to \$150/yd^3 (D15723N, p. 34).

Information Source

D15723N, VISITT 5.0, 1996

T0524

Microbes Research and Development, Inc.

Uremel

Abstract
Uremel is a granular biological sorbent and bioremediation accelerator composed of carbon, nitrogen, phosphorous, potassium, trace elements, wetting agent, water, and air. It is applied to

spills in which hydrocarbons and water-based liquids are the target contaminants, such as at petrochemical refineries, oil production sites, oil and fuel storage facilities, and drilling sites.

Uremel is commercially available and has been used in field applications. It is available through agents, dealers, and distributors.

According to the vendor, Uremel absorbs liquids through capillary encapsulation; once the liquid is absorbed, it is encapsulated inside the Uremel granules. Uremel is able to absorb free flowing liquids, as well as stagnant liquids. The vendor claims that once a liquid is encapsulated, the liquid will not leach out. The sorbent is 100% biodegradable according to the vendor.

This technology is only appropriate for use with hydrocarbon contamination; it is not intended for other organics, metals, or other inorganics.

Technology Cost

A 1997 price list for Uremel Granulate is given in Table 1. A listing of Uremel boom, sock, and pad options are listed with prices in Table 2 (D17135H, p. 4–5).

According to the vendor Uremel granules will absorb up to 60:1 by weight and 1:1 by volume. These ratios will vary based on the target liquid. One cubic yard Uremel will absorb five barrels of crude oil (D17135H, p. 2).

Information Source

D17135H, Microbes Research and Development, web page

TABLE 1 Uremel Granulate Price List

Units	Description	Cost
1.0 yd^3	2.5-yd^3 3-mil bags	$75.00/bag
0.5 yd^3	1.5-yd^3 3-mil bags	$85.00/bag
3.0-ft^3 bag	4 bags/box	$24.00/bag
1.0-ft^3 bag	14 bags/box	$8.00/bag
10+ yd^3	20+ 1.5-yd^3 3-mil bags	$65.00/bag
20-ft container load	72 1.5-yd^3 3-mil bags	$55.00/bag
40-ft container load	144 1.5-yd^3 3-mil bags	$45.00/bag

Source: From D17135H, p. 4.

TABLE 2 Uremel Boom, Sock, and Pad Options and Prices

Unit	Description	Price
20-ft × 6-inch boom	4 booms w/cotton shell/box	$57.00/boom
10-ft × 6-inch boom	8 booms w/cotton shell/box	$29.00/boom
10-ft × 4-inch boom	16 booms w/cotton shell/box	$21.00/boom
10-ft × 3-inch Sock	24 socks w/cotton shell/box	$11.00/sock
24-inch × 22-inch × 1.5-inch pad	16 pads w/cotton shell/box	$10.00/pad
18-inch × 16-inch × 1.5-inch pad	12 pads w/cotton shell/box	$7.00/pad
12-inch × 10-inch × 1.5-inch pad	8 pads w/cotton shell/box	$5.00/pad
18-inch × 8-inch sump sock	12 sump socks w/cotton shell/box	$7.00/sock
18-inch × 4-inch sump sock	20 sump socks w/cotton shell/box	$4.00/sock
18-inch × 2.5-inch skimmer	30 well skimmers w/cotton shell/box	$2.50/sock
14-inch × 20-inch fuel bibb	10 bibbs w/cotton shell/box	$7.00/bibb

Source: From D17135H, p. 5.

T0525

Microbial Aquatic Treatment Systems, Inc. (MATS)

Biomats

Abstract

Microbial mats, also known as Biomats™, are a biological remediation technology used to treat both organic and inorganic contaminants in water. The mats are self-organizing structures that can be generated quickly by enriching a water surface with fermenting vegetative matter, such as grass clippings. They are held together by filamentous cyanobacteria (blue-green algae), which give the mat its slimy, leathery appearance and its resilience. The mats support aerobic (with oxygen) and anaerobic (without oxygen) microorganisms that are capable of degrading or sequestering contaminants. Microbial mats have exhibited excellent durability in the field, are efficient under fluctuating environmental conditions, and do not require outside sources of nutrients. In addition, they can be designed for specific target contaminants by adding microbes that are known to degrade the those compounds. Microbial mats are commercially available on a pilot-scale basis.

Microbial mats are designed to remove radionuclides, heavy metals, chlorinated pesticides, and petroleum compounds. Mats have been or are being tested at sites for the treatment of the following contaminants: manganese from coal mine drainage, metals from gold and silver mine drainage, gasoline in groundwater pumped from a contaminated aquifer, and leachate from a landfill. Vertically hanging Biomats have also been evaluated for the treatment of radionuclides.

High water flow rates or excessive turbulence are factors that can limit the success of microbial mats. In a field-scale experiment, a 50-cm snowfall flow dramatically increased water flow rates in the mat pond, causing severe damage to the mat. As a result, the pond had to be drained and reinoculated. Snails and other invertebrate herbivores have also been known to damage the mats.

Technology Cost

No information available.

T0526

Microbial Environmental Services, Inc. (MES)

Bioremediation

Abstract

Microbial Environmental Services (MES) uses bioremediation for treating hydrocarbon contamination in soil and groundwater, in situ or ex situ. For ex situsoil treatment, the Advanced Biological Surface Treatment (ABST), which has a "burrito-type" lining to prevent the volatilization of the contaminants, is used. For the in situ soil treatment, low concentrations of nutrients and oxygen are introduced into the subsurface with infiltration galleries. The system is hydraulically controlled to prevent migration of the contaminants and nutrients from the treatment site. For in situ groundwater treatment, recovery wells are used for extraction. This technology is no longer commercially available.

This technology is not applicable to nonbiodegradable wastes, including wastes containing only metals, inorganic cyanide wastes, inorganic corrosive wastes, and wastes containing radioactive materials. It is also not applicable to the treatment of polychlorinated biphenyls (PCBs) or dioxins and furans. At one site where the aquifer temperature drops to 6 to 8°C in the winter, the microbial activity slowed down during the cold temperatures.

Technology Cost
While the cost of bioremediation can vary widely depending on site conditions, the developer estimated the following cost ranges:

- In situ soil, \$50 to \$125/yd^3 (D102794, p. 13)
- In situ groundwater, \$40 to \$100/yd^3 (D10280X, p. 15)
- Solid phase, \$20 to \$75/yd^3 (D102783, p. 24)

Information Sources

D102794, VISITT 4.0, 1995
D10280X, VISITT 4.0, 1995
D102783, VISITT 4.0, 1995

T0527

Microfluidics Corp.

Microfluidizer

Abstract
The Microfluidizer™ is a technology used to create uniform, submicron structures and microemulsions in soils and sludges to enhance treatment by other remediation technology. According to the vendor, the technology is currently used in health care, chemical, food, coatings, and many other industries where high-performance mixing, formulation, dispersion, and disruption effects are specified. The vendor claims that over 1000 systems are currently in routine operation.

Because feed material must flow through the equipment, heating must be provided for viscous or solid materials. All information is supplied by the vendor and has not been independently verified.

Technology Cost
No available information.

T0528

Midwest Soil Remediation, Inc.

GEM-1000 Low-Temperature Thermal Desorption

Abstract
The GEM-1000 low-temperature thermal desorption unit is an ex situ technology that treats soils contaminated with volatile organic compounds (VOCs). This process involves a countercurrent drum, pulse-jet baghouse, and a catalytic oxidizer mounted on a single portable trailer. As the soil is heated in the GEM-1000 unit, contaminants are vaporized. The contaminants are then directed to the system's catalytic oxidizer, which is designed to convert virtually all of the VOCs to carbon dioxide and water vapor. The oxidizer contains approximately 4.9 ft^3 of noble metal catalyst and can destroy between 95 and 99% of the hydrocarbons when operating between 600 and 1250°F.

The GEM-1000 process has been used in the field to treat acetone, 1,1-dichloroethylene (DCE), methylene chloride, 1,1,2-trichloroethane (TCA), as well as benzene, toluene, ethylbenzene, and xylenes. This technology has been applied at multiple sites and is commercially available.

Thermal desorption technologies have several potential limitations. Inorganic contaminants or metals that are not particularly volatile will not be effectively removed by the process. If chlorine or another chlorinated compound is present, some volatilization of inorganic constituents in the waste may also occur. Caution should also be taken regarding the disposition of the material treated by thermal desorption because the treatment process may alter the physical properties of the material.

Technology Cost

According to the vendor, the cost of using GEM-1000 ranges from $30 to $150 (1995 dollars) per ton of media treated. This estimate may not include all indirect costs associated with treatment, such as excavation, permits, and treatment of residuals (D102761). A GEM-1000 unit costs approximately $750,000. In 2001, a second-hand GEM-1000 unit built in 1990 listed for $190,000 (D22267D, p. 1; D22268E, p. 1).

The following factors can influence treatment costs:

- Quantity of waste
- Initial contaminant concentration
- Moisture content of soil
- Amount of debris in with waste
- Waste handling/preprocessing
- Characteristics of residual waste
- Target contaminant concentration
- Characteristics of soil (D102761, p. 34)

Information Sources

D102761, VISITT Version 4.0, 1995
D22267D, Trans World Equipment Sales, 2001
D22268E, Global InterMark Corporation, 2001

T0529

Millgard Corporation

MecTool Remediation System

Abstract

MecTool™ is essentially a mixing and blending aid that helps overcome the mass transfer limitations associated with many in situ waste treatment technologies. The remediation delivery system consists of mobile equipment that includes a soil boring and mixing tool with high-capacity injection/extraction capability. MecTool treats fine-grained soils contaminated by volatile organic compounds (VOCs) in situ. This system works to enhance the performance of other remediation technologies including dynamic air sparging, bioremediation, and stabilization/solidification.

This technology is currently commercially available.

Vendors and researchers list the following advantages of MecTool technology:

- Allows for in situ treatment of contaminants.
- Can be used to enhance the performance of several in situ technologies, including bioremediation, in situ chemical oxidation, in situ thermal treatments, and in situ solidification.
- Can be used to remediate contaminants in soils, sludges, and underwater sediments to a maximum depth of 100 ft.
- is available in several sizes for specific site needs.

Subsurface obstructions and dense soil or waste layers may cause tool rotation to halt. Shallow obstructions (<20 ft deep) should be excavated prior to applying the MecTool system.

Technology Cost

The estimated price for this technology is \$40 to \$150/yd^3 of waste material. These price estimates do not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals. Table 1 presents actual cost data from several remediation projects (D13751J).

When using the MecTool to remove trichloroethene using heated air injection, the cost per cubic yard is estimated to be \$138. When using steam injection followed by heated air injection, the cost per cubic yard increases to \$160. When treating soil contaminated with methyl ethyl ketone (MEK), the cost for removal with heated air is \$181/yd^3. Using steam injection followed by heated air injection, the cost decreases to \$160/yd^3. (D185664, p. 93).

In a review of deep soil mixing techniques, Bruce et al. stated that large-scale soil mixing systems may cost \$80,000 to \$200,000 to mobilize (costs were reported to be lower for methods such as lime cement columns). Typical treatment prices for deep soil mixing technologies were estimated to range from \$50 to \$100/m^3 (D207238, p. 4).

Factors that have a significant effect on unit price include the following:

- Characteristics of soil
- Amount of debris with waste
- Quantity of waste
- Depth of contamination
- Labor rates
- Site preparation
- Moisture content of soil
- Target contamination concentration
- Initial contaminant concentration

TABLE 1 Vendor-Supplied Cost Data from Remediation Projects Using the MecTool Soil Mixing System

Site	Cost
Geiger (C and M) Oil Superfund Site, Charleston, South Carolina	\$70/yd^3
British Petroleum, Pumpherston Station, Scotland	\$83/yd^3
Wisconsin Fuel and Light, Manitowoc, Wisconsin	\$135/yd^3[a]
Portsmouth Gaseous Diffusion Plant, Piketon, Ohio	\$8000 daily rate to conduct test
Masselink Electroplating, Grand Rapids, Michigan	\$87/yd^3

Source: From D13751J, Milgard Environmental Corporation, vendor literature.
[a] Grout mix cost = \$375/yd^3.

- Utility/fuel rates
- Depth to groundwater
- Characteristics of residual waste (D12910C, p. 33).

Information Sources

D12910C, VISITT Version 5.0, 1996
D13751J, Millgard Environmental Corporation, vendor literature
D185664, Funk and Taylor, date unknown
D207238, Bruce et al., undated

T0530

MIOX Corporation

MIOX System

Abstract
The MIOX system is a technology that generates mixed oxidant disinfectants using only salt, 12-V direct current, and an electrolytic cell. By using this technology, oxidants and free available chlorine can be generated on-site for water disinfection and aqueous waste treatment.

This technology has potential uses for industrial process waters; cooling towers; meat, fruit, and vegetable processing; swimming pools; potable water; biofilm/biofouling removal; odor control; iron and manganese removal; and for groundwater remediation.

The vendor claims that this technology can break down groundwater contaminants including the following: toluene, ethylbenzene, xylene; volatile organic compounds (VOCs); fuel hydrocarbons; and cyanides in industrial wastes. It can also destroy pathogenic organisms.

This technology is currently commercially available from the MIOX Corporation, an affiliate of Los Alamos Technical Associates, Inc. While the MIOX system for disinfection applications is fully commercialized, applications for environmental remediation and Resource Conservation and Recovery Act (RCRA) waste treatment are still in the early stages of development.

Water conditions, such as temperature, alkalinity, iron levels, and manganese concentrations are all factors that can potentially affect the generation of mixed oxidants and the overall performance of the disinfection process. Some adjustment of the concentration of the mixed oxidant solution may be necessary to prevent scaling in hard-water areas.

Technology Cost
The MIOX Corporation prepared cost estimates on the MIOX system based on bench-scale testing. They estimated that the active mixed oxidant solution produced by the process costs about 7 cents/gal to produce, including the costs of power, salt, and electrolytic cell recycling. At an injection ratio of 1 to 500, two gallons of mixed oxidants would be required to treat 1000 gal of water. The amount of mixed oxidants required varies with each individual waste stream, and with the treatment goals, so this estimate is by no means universal (D15848Z, p. 114).

The capital cost of an installed "SAL-80" generator, which can treat 1.2 million gallons per day at 1 part per million (ppm) [production of 10 lb free available chlorine (FAC) per day], is $22,347.88. Operating costs for this unit are $15.36 per day, or $5,606 per year, including the costs of salt, electricity, and replacement cells (D157986, p. 6).

Another estimate by MIOX states that the capital cost for a SAL-80 is $19,000. For a system treating 1 million gallons per day at 1 ppm FAC per day, operating costs are estimated as $0.0073 per 1000 gal of treated water, and annual maintenance costs are estimated to be $2000, including parts, safety training labor, safety equipment, and insurance costs. Total costs amortized over 10 years are estimated to be $65,645 (D176572, p. 4).

Information Sources

D157986, Bruce Dobbs, 1996

D15848Z, Ground Water Monitor, 1995

D176572, MIOX Corporation, 1997

T0531

Mirage Systems, Inc.

ChemChar Process

Abstract

The ChemChar process is a patented, ex situ method for the treatment of hazardous and mixed wastes using reverse-burn gasification. Organic components of the treated waste are converted to a combustible gas and a dry, inert solid. The solid can be mixed with cement to prevent leaching of radioactive or heavy-metal constituents retained in the char residue after gasification, or the solid can be further reduced by forward-burn gasification.

The ChemChar process can be used to treat soil, sludge, sand, rock, tailings and polymeric materials that contain a hazardous component. Waste material treated by the ChemChar process can include almost any nonexplosive inorganic fraction and may include thermochemically destructible organics and/or inorganics. The technology is particularly well suited for the treatment of soils and sludges containing halogenated organics, and for the treatment of organic resins containing low levels of radionuclei and organic contaminants from nuclear reactor cooling water. This technology can also be used for the regeneration of activated carbon. The technology is no longer commercially available.

Strong oxidants such as ammonium perchlorate or other highly reactive species such as hydrides should be limited or excluded from the ChemChar process to prevent a runaway reaction or explosion. Wastes can be pretreated to remove such compounds prior to treatment with ChemChar.

The developer claims the following advantages to the ChemChar technology:

- Treats mixed waste without producing hazardous by-product compounds in secondary waste.
- Reduced need for off-gas treatment compared to competing technologies, such as plasma arc vitrification, molten salt, and metal melting technologies.
- Reduced secondary waste volume.

Technology Cost

There is no available information regarding the costs associated with the ChemChar process.

T0532

Modified Clays as Adsorbents — General

Abstract

Modified clays comprise a commercially available ex situ technology that can remove low-solubility organics from groundwater. Smectites (including montmorillonite and bentonite clays),

which are naturally occurring clays measuring less than 2 μm in diameter, are chemically modified to produce a hydrophobic material. The modification process entails mixing the clay with a quaternary amine, isopropyl alcohol, and water. This replaces the clay's natural cations with the quaternary amine.

The resulting modified clay is used to adsorb organic contaminants. This technology can be used as a primary treatment, pretreatment, or posttreatment. As a primary treatment, the technology can only treat organics with low water solubility such as polychlorinated biphenyls (PCBs), pentachlorophenol, or pesticides. Pretreatment applications include remediation of gasoline spills, mixed solvents, and coal gasification wastes. In posttreatment applications, the technology often follows oil–water separators, ultrafiltration units, or biotreatment units to assure discharge quality.

Technology Cost

No available information.

T0533

Molasses Treatment for Bioremediation — General

Abstract

Molasses has been used as a nutrient source to encourage the anaerobic bioremediation of soil and groundwater contaminated with metals, explosives, and chlorinated solvents. The nutrient source can be added to excavated, screened soil, or injected directly into the subsurface via wells. Several vendors and developers have conducted bench-, pilot-, and full-scale demonstrations of the technology. Some of the molasses technologies are commercially available.

The anaerobic bioremediation of highly chlorinated compounds may generate intermediate products that are more mobile and more toxic than the original compound. Heterogeneties in the subsurface may cause the uneven distribution of nutrients during direct-inject applications. The process operates at pH values between 6 and 8. Cold temperatures slow the rate of biodegradation.

Technology Cost

Molasses has been used in slurry-phase bioreactors to encourage the bioremediation of explosives. The costs of this ex situ system were calculated based on the pilot-scale demonstration at the Joliet Army Ammunition Plant in Joliet, Illinois. The projected costs of a full-scale remediation using the slurry-phase treatment system ranged from \$290 to \$350/yd^3 (D210571, p. 67).

Molasses has also been applied directly to the subsurface using injection wells. The groundwater at the 2-acre Avco Lycoming Superfund Site in Williamsport, Pennsylvania, was contaminated with chlorinated solvents, cadmium, and hexavalent chromium. Following a successful, 2-year pilot-scale demonstration that lasted from 1995 through 1996, the ARCADIS Geraghty and Miller, Inc., in situ reactive zones using molasses technology was used in the full-scale remediation of the site. The cost of the pilot-scale demonstration was approximately \$145,000. The full-scale remediation system cost about \$220,000 to construct. Operation and maintenance costs have been approximately \$50,000 per year (D210571, p. 93; D213376, p. A-47).

Information Sources

D210571, Federal Remediation Technologies Roundtable, 2000

D213376, U.S. EPA, 2000

T0534

Molten Metal Technology

EnviroGlass

Abstract
The EnviroGlass™ technology is designed to stabilize low-level radioactive wastes (LLRW) in glass matrix for disposal. According to the vendor, applicable wastes include dry active wastes (DAW), ion exchange resins, chemical cleaning and decontamination solutions, inorganic sludges and slurries, medical wastes, and mixed wastes.

According to the vendor, this technology is commercially available.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0535

Molten Metal Technology, Inc.

Quantum Catalytic Extraction Process

Abstract
Molten Metal Technology, Inc., has developed the quantum catalytic extraction process (Q-CEP) for the treatment of radioactive and mixed wastes. Q-CEP is derived from catalytic extraction process (CEP) technology in which a bath of molten metal is used as a catalyst to dissociate materials into elemental forms. Wastes are fed into the system at high temperatures and near atmospheric pressures. These wastes normally produce (in differing proportions) metal; ceramics; and off-gases consisting of volatile metals, hydrogen, hydrochloric acid, and carbon monoxide. According to the vendor, Q-CEP technology partitions radionuclides with decontamination factors greater than 99%, allowing for significant volume reduction and stabilization of radioactive and mixed wastes. The technology is commercially available.

According to the vendor, the main advantages of Q-CEP technology are as follows:

- Requires only one step to process wastes.
- Destroys organic contaminants.
- Recovers metals.
- Partitions radionuclides.
- Achieves volume reductions ranging from 2 : 1 to 1000 : 1.

Some radioactive metals (e.g., cesium) are highly volatile under Q-CEP operating conditions. Predrying may be required for liquids with high water contents. Solids may require shredding or milling prior to treatment. Extensive treatment of off-gases is required.

Technology Cost
No available information.

T0536

Molten Salt Oxidation — General

Abstract
Molten salt oxidation (MSO) is an ex situ noncombustion thermal treatment technology. MSO technology is under development for hazardous, radioactive, and mixed wastes (wastes with

both hazardous and radioactive components). MSO technology is potentially applicable to solid wastes, aqueous wastes, and for treatment of off-gases from other thermal technologies, such as incineration and pyrolysis. It is not commercially available at this time.

MSO research is currently funded by the Department of Energy (DOE), and pilot-scale and bench-scale projects are underway. There is a 5-year development plan for MSO, leading to a projected full-scale demonstration of the technology in fiscal year 1997.

In MSO processing, organic wastes are chemically broken down to carbon dioxide, nitrogen gas, and water vapor in a bath of molten salt. The salt may be of various compositions, with variable melting points. Inorganic materials react with the salt mixture, producing ash and salts for subsequent treatment or disposal. The oxidation takes place at lower temperatures than incineration or other combustion technologies.

MSO technology can achieve complete oxidation of contaminants because of the relatively long residence time (1 to 2 sec) in the molten salt bed. MSO technology offers several advantages, relative to incineration, for treatment of many wastes, including eliminating the need for a wet off-gas scrubbing system. In addition, the molten salt mixture is resistant to thermal surges, as there is no need to account for flame variation. MSO treatment systems could be constructed for small-quantity facilities. MSO is believed to have a limited release potential for fugitive radionuclides.

MSO is unsuited for treating materials with high inert content, such as asbestos, concrete, soils, and rubble. There is concern over emissions from MSO relating to particulate mercury content and radioactivity. MSO is inappropriate for wastes with high tritium levels. MSO pilot programs have encountered problems with carbon monoxide (CO) emissions. The corrosion of reactor materials by molten salt has remained a concern for the long-term operability of the system. The viscosity and volatility of the melt have to be controlled. There have been problems with material from the melt plugging air exhaust and feeder systems.

Technology Cost

It is estimated that the cost of treatment using MSO technology will be relatively high, due to high capital costs, labor requirements, and energy costs required to reach process temperatures. The cost per ton will be heavily dependent on process throughput and the chlorine content of the treated waste (D18091Q, pp. 9, 10).

Information Source

D18091Q, Environment Australia, 1997

T0537

Monsanto Company

Lasagna

Abstract

Lasagna™ is the trademarked name of a patented in situ process for the treatment of low-permeability soils and soil pore water contaminated with soluble organic compounds. The technology is being developed by a consortium comprising the Monsanto Company, E.I. DuPont de Nemours & Co., Inc. (DuPont), and General Electric, with participation from the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA).

Lasagna uses electro-osmosis to mobilize contaminants into installed in situ treatment zones where contaminants are removed by adsorption, immobilization, or degradation. The technology is currently undergoing field demonstrations and is not yet commercially available. It will be marketed by Envirogen, a subsidiary of Monsanto Company.

The technology has proven effective in bench-scale tests for the treatment of trichloroethylene (TCE), dichloroethane (DCA), and *p*-nitrophenol (PNP) and can potentially treat a variety of organic, inorganic, and mixed wastes. Bench-scale and pilot-scale field tests have been conducted, and further testing of the Lasagna process is in progress.

Technology Cost

The cost of a vertical Lasagna system was evaluated by DuPont using a cost optimization model. For remediation of TCE to a depth of 40 to 50 ft (12 to 15 m) in clay on a 1-acre (4047-m^2) site, costs were estimated to range from \$40 to \$90/yd^3 (\$52 to \$117/m^3). Soil properties, depth of contamination, cost of emplacing electrodes and treatment zones, required purge water volume, cleanup time, and cost of electrical power were all included in the estimate (D12500Y, p. 10).

The cost-optimized electrode spacing for electro-osmosis is 3 to 6 m for most soils. This allows cleanup within a reasonable time (less than 5 years) while avoiding soil overheating. Electrode construction is a major factor in overall application cost—generally 20 to 40%. Lasagna reduces the cleanup time and power input by inserting treatment zones between the electrodes. The ability to emplace treatment zones and electrodes in relatively close spacing and at reasonable cost is critical to the cost-effectiveness of the technology (D12500Y, p. 10). Table 1 summarizes the estimated cost of Lasagna compared to other remediation options.

In 1998, an evaluation of Lasagna technology was prepared for the U.S. EPA's Rapid Commercialization Initiative. As part of the evaluation, cost estimates were prepared. An example of one of these estimates is given in Table 2. These estimates were determined for core costs only, as noncore costs such as oversight, health and safety, sampling, and quality assurance/quality control can vary significantly from one site to the next. The number of pore volumes of water

TABLE 1 Estimated Cost of Comparable Remediation Options

Technology	Cost/yd^3	Cost/m^3	Total Cost
Lasagna	\$40–\$90	\$52–\$117	\$5,010
Soil heating/vapor extraction	\$65–\$88	\$85–\$115	\$10,600
In situ chemical oxidation	\$99–\$153	\$130–\$200	NAI[a]

Source: From D12500Y, p. 9 and D18443U, p. 2.
[a]NAI, no available information.

TABLE 2 1998 Estimated Cost Breakdown Based on a Full-Scale Site Remediation Using Lasagna Technology[a]

Cost Element	Estimated Cost	Cost/yd^3	Percent of Total Cost
Pretreatment sampling and design	\$20,000	\$2.00	1.2
Site preparation	\$25,000	\$2.50	1.5
Electrode, treatment zones, and equipment installation	\$1,050,000	\$105.00	61.0
Operation and maintenance	\$502,000	\$50.20	29.1
Project management	\$100,000	\$10.00	5.8
Site restoration	\$25,000	\$2.50	1.5
Totals	\$1,722,000	\$172.20	100.1

Source: Adapted from D18418T.
[a]This estimate is based on the following assumptions: that 4 pore volumes will be required to remediate the site, that the site requires 3 years of treatment, and the total volume of contaminated soil is 10,000 yd^3. The dimensions of the site are assumed to be 60 ft wide, 100 ft long, and 45 ft deep.

TABLE 3 Estimated Lasagna Remediation Core Costs per Cubic Yard as a Function of Depth, Pore Volumes (PVs) Required, and Years Allowed for Remediation

	Remediation Costs in Dollars			
Years Allowed	2 PV @ 15 ft	4 PV @ 15 ft	2 PV @ 45 ft	4 PV @ 45 ft
1	$189	$258	$138	$206
2	$200	$237	$132	$165
3	$205	$239	$122	$156
4	$215	$256	$117	$157
5	$213	$265	$119	$160

Source: Adapted from D18418T.

required to clean the site has a profound impact on treatment costs. Treatment costs in Table 2 list a total cost of $172.20/yd^3 for wastes requiring 4 pore volumes of water. If it is possible to clean the site using only 2 pore volumes of water, treatment costs drop to $137/yd^3 (D18418T, p. H-1). Core costs as a function of depth, pore volumes required, and years allowed for remediation are summarized in Table 3.

Information Sources

D12500Y, U.S. DOE, April 1996

D18418T, U.S. EPA, 1998

D18443U, General Electric, web page, 1998

T0538

Montana Tech of the University of Montana

Campbell Centrifugal Jig

Abstract

The Campbell centrifugal jig (CCJ) is a mechanical device that uses centrifugal force to separate fine heavy mineral and metal particles from waste materials. The CCJ combines jigging and centrifuging to separate these particles from a fluid slurry. The CCJ can separate and concentrate a wide variety of materials, ranging from base metals to fine coal ash and fine (1-μm) gold particles. Applications include remediation of heavy metal-contaminated soils, radioactive materials, tailings, or harbor areas containing spilled concentrates; removal of pyritic sulfur and ash from fine coal; and treatment of some sandblasting grit.

This technology is currently commercially available but is not being used for site remediation. The CCJ is currently being used for fine gold recovery. This technology is protected under U.S. Patents 4,279,741 and 4,998,986.

Technology Cost

As part of the U.S. Department of Energy (DOE) Heavy Metals in Contaminated Soils Treatability Project, total operating cost for the Campbell centrifugal jig is $1.07 per ton (1995 dollars). Capital costs to lease the centrifugal jig are estimated at $16,000 per month or $0.64 per ton. Costs considered in this operating cost estimate include the following:

- Capital equipment costs
- Installation costs

- Power costs
- Reagent costs
- Maintenance costs

Assumptions used include the following:

- The unit has a processing rate of 40 to 50 tons per hour.
- All operating costs are expressed in constant dollars terms; outyear costs are not adjusted for inflation.
- Capital costs are amortized over 10 years at a 7% discount rate.
- Installation costs are estimated at 150% of equipment costs.
- Power costs are estimated using a retail electricity rate of $0.06/kWh.

Costs not included in this estimate include the following:

- Soil excavation
- Transportation
- Waste disposal
- Facility infrastructure (D14800F, pp. 41, 44)

Information Source

D14800F, MSE, Inc., 1995

T0539

Mountain States R & D International, Inc.

MSRDI Combination Technology Mercury Treatment System

Abstract

Mountain States R & D International, Inc. (MSRDI), has developed the MSRDI combination technology mercury treatment system to remove mercury from contaminated soils. This pilot-scale system consists of several unit operations, including crushing, mixing, screening, and gravity separation to remove elemental mercury and chemical leaching, filtration, and rinsing steps to recover solubilized mercury. The technology was evaluated in 1994–1995, as a pilot-scale, batch-mode process, and is not currently commercially available.

The vendor claims that MSRDI technology allows for more effective treatment of mercury-contaminated soils than physical separation techniques alone, especially when mercury is present in organic or ionic forms.

The vendor claims that while the process is technically sound, it will require a high degree of system engineering prior to any commercial application.

Technology Cost

A 1995 evaluation prepared by MSRDI and the Gas Research Institute (GRI) estimates that the capital costs for a portable MSRDI combination technology mercury treatment system would be approximately $400,000. Direct operating costs for a portable system controlled by two technicians and a supervisor were estimated to be $1600 per day of operation, assuming a treatment rate of 2 to 4 tons of contaminated material per day per site, Overall operating costs were estimated to range from $400 to $800 per ton, per site, including mobilization and demobilization costs (D16195P, p. 35).

Information Source

D16195P, Gas Research Institute, 1995

T0540

MSE Technology Applications, Inc.

Viscous Barrier Technology

Abstract

MSE Technology Applications, Inc. (MSE-TA), has developed a viscous barrier technology using materials such as colloidal silica, polysiloxane, and polybutane. These materials, also known as grouts, are injected into the soil matrix displacing pore water and filling pore spaces. When the materials gel, they form an impermeable barrier that is both nonreactive and unaffected by filtration. This technology is still in development and is not commercially available.

According to the U.S. Department of Energy (DOE), the viscous barrier technology has the following advantages:

- The barrier can improve pump-and-treat efficiency by isolating contaminant sources.
- Installation does not require excavation and causes little or no destruction of the soil matrix.
- The technology can be installed in a number of configurations, allowing for containment at sites where conventional barrier methods are inadequate.
- There are no spoils to be treated.
- Barrier materials are biologically and chemically inert.
- The technology is applicable to a range of contaminants including radionuclides, heavy metals, organics, and mixed waste.
- The technology can be used alone or in conjunction with treatment techniques.

Several factors may limit the application of viscous barrier technology. The technology is not effective in clay soils, and cooler subsurface temperatures may slow barrier gelling. In addition, the barrier material may desiccate over time.

Technology Cost

The cost of the 1997 Brookhaven National Laboratory (BNL) demonstration of viscous barrier technology was $593,000. This cost included expenses associated with equipment, grout materials, labor, and emplacement. Site-specific expenses such as project management, permitting, engineering support, engineering design, and site characterization were not included in the total. The cost of viscous barriers varies according to grouting method, drilling method, depth of drilling, and grouting materials (which all depend on site characteristics). A preliminary study showed a 54 to 59% cost savings compared to slurry walls (D18895I, p. 2). Another study performed by MSE Technology Applications, Inc., for the U.S. Department of Energy (DOE) indicated that costs of viscous barrier technology are six times less than costs of excavation and disposal (D22201V, p. 3).

Information Sources

D18895I, U.S. DOE, 1998
D22201V, U.S. DOE, 2000

T0541

MYCELX Technologies Corporation

MYCELX

Abstract

MYCELX is a proprietary chemical that removes organic and inorganic contaminants from wastewater, groundwater, and surface water. According to the vendor, the chemical can be applied to a variety of substrates and used to treat contaminated water in situ. MYCELX has a high affinity for organic compounds and a low affinity for water but can treat waters contaminated with both water-soluble and water-insoluble compounds.

Products using the patented MYCELX chemistry are available in a number of forms for various field site-specific applications, including booms for water surface; pads for deeper water and land application; loose, such as on wood chips, for various water (including wetlands) and land applications; and the Terraguard™ shoreline protection system. The Terraguard system is a dual material usage that contacts both the bottom of the water body and the surface of the water to prevent oil from reaching a shoreline. These products are commercially available and have been used in multiple full-scale applications.

The vendor sites the following as important characteristics of their MYCELX products:

- Lightweight substrates allow for easier handling and lower disposal costs.
- Buoyant materials are used to allow the product to be used for extended periods, maximizing product life, and keeping sorbed oils from sinking.
- Products are designed to maximize the area that is in contact with the contaminated surface.
- A minimum of water attaches to the product, which keeps disposal weight low and Btu values high (if the product is incinerated).
- Compound does not re-release contaminants into the water until saturation is reached.

The information used in the preparation of this summary was provided by the vendor and has not been independently verified. MYCELX is unable to treat waters contaminated with water-soluble organic compounds containing fewer than 6 carbons. The target oil contaminant is absorbed onto the MYCELX oil absorbent, making it easier to collect and dispose of, however, the hazardous nature of the oil is not altered and the oil-soaked absorbent must be disposed of according to whatever regulations apply to the oil.

Technology Cost

MYCELX is a proprietary chemical that can be applied to a variety of substrates to remove organic and inorganic compounds from contaminated surface water, groundwater, and wastewater. The substrates are selected based on the application and marketed as individual technologies. The prices and brief descriptions of several products are provided in Table 1 (D17717X; D220633).

According to the vendor, MYCELX systems can be used to remove sheen from contaminated surface waters for approximately \$0.01/gal (D220699, p. 8).

At a utility company, a treatment train consisting of 2 particulate bag filters and 2 MX-4 MYCELX-infused particulate bag filters were installed to treat 950,000 gal of storm water contaminated with polychlorinated biphenyls (PCBs). Treatment costs were approximately 2.8 cents/gal (D220451, p. 40).

A comparison of a 10-ft section of 8-inch diameter 3M melt blown polypropylene boom versus a 10-ft section of the MYCELX Sheen Devil™ product resulted in a cost per effective area of \$100/ft^2 for the 3M product and \$3.10/ft^2 for the Sheen Devil.

TABLE 1 MYCELX Oil Absorbent Products Cost and Description

Product	Number per Box	Factory Direct Price	Suggested Retail Price	Size	Application
Versipad	50	\$124.95	\$149.95	14 inches × 21.5 inches	Unfoldable to 18.2 ft^2
Smartpad	50	\$149.95	\$199.95	13.75 inches × 21 inches	Will not bleed through
Superbuoyant RD	5	\$199.95	\$249.95	12 ft interconnectable lengths	For heavy/group V oils and film
Sheen Devil	4	\$179.95	\$299.95	10 ft interconnectable lengths	Superbuoyant oil and sheen boom
Terraguard	2	\$199.95	\$249.95	10 ft interconnectable lengths	Shore line protection system
Fullcycle	12	\$119.95	\$143.95	12-ounce cans	Crude and heavy oil solvent
Viscochips	25 lb	\$145.95	\$199.95	25 lb	Viscoelastic rheology modifier
Versimat	4	\$169.95	\$395.95	10 ft interconnectable lengths	Large-scale light to heavy oil absorption
FuelKleen	10	\$40.95	NA[a]	NA	Collar designed to catch fuel drips from pumps at boat fueling stations
VentKleen	1	\$129.85	NA	NA	Catches splashes from boat fuel vents during fueling operations
Boater Emergency Spill Kit	1	\$29.95	NA	20 Smartpads, 1 bag of Viscochips, gloves, disposal bag	Helps boaters clean up small spills
BILGEKLEEN	1	\$99.95 (unit) \$34.85 (refills)	NA	NA	Removes hydrocarbon contamination from bilge water on boats

Source: From D17717X and D220633.
[a]NA, not available.

Information Sources

D17717X, Mother Oil Remediation Products, undated
D220633, MYCELX Technologies Corporation, 2001
D220699, Alper, 2000
D220451, Alper and D'Angelo, 2001

T0542

Mycotech Corporation

Fungal Bioremediation

Abstract
Mycotech offers a fungal bioremediation technology that uses white-rot or other types of fungi to degrade many organic contaminants in soil. The technology can be applied in situ for shallow contamination (up to 18 inches) or ex situ for deeper contamination. Mycotech's fungal bioremediation technology is the result of 10 years of research and development. The ability of white-rot fungus to degrade organic compounds has been well documented through laboratory-scale experiments over the last 15 years. No case study information was available from any full-scale applications.

Mycotech has performed multiple pilot-scale field tests; however, the company no longer performs remediation, and the technology is no longer commercially available.

Mycotech's fungal biotreatment relies on fungi that degrade lignin, a tough, structural component of wood. Under the proper conditions, these fungi release an enzyme that degrades the lignin, which they use for food. The enzyme has been found to degrade many complex, recalcitrant contaminants such as petroleum hydrocarbons, crude oil, pentachlorophenol (PCP), creosote, polynuclear aromatic hydrocarbons, pesticides, explosives, polychlorinated biphenyls (PCBs), and other compounds, many of which have traditionally been difficult to degrade with bioremediation technologies. The technology can be applied ex situ in a landfarming scenario.

Depth of in situ applications is limited to 18 inches. Other soil parameters, such as pH, temperature and moisture, and oxygen, carbon dioxide, and nutrient levels must be kept within ranges determined during treatability studies,.

It is unclear from the current data if the fungal bioremediation technology will be able to reduce all contaminant concentrations to below regulatory levels. In the PCP field test at the Montana Pole Plant, total detectable chlorinated phenolics (PCP and pentachloroanisole) decreased to 230 and 119 mg/kg (decreases of 78 and 84%, respectively) in the high and low plots. While

TABLE 1 Mycotech Fungal Bioremediation Cost Comparison

Technology	Estimated Cost for Treating a Cubic Yard of Soil
Incineration	\$350–\$1500
Solvent extraction	\$360–\$1000
Encapsulation	\$300–\$750
Landfill	\$250–\$600
Fungal bioremediation	\$75–\$300

Source: From D122714.

these are significant reductions, they may not have lowered contaminant concentrations to below regulatory levels.

Technology Cost
Table 1 compares remediation cost estimates per cubic yard of soil for several technologies, as provided by Mycotech (D122714, p. 4).

Information Source

D122714, vendor literature

T0543

Naiad Technologies, Inc.

RadAway

Abstract
RadAway™ is a technology for the treatment of liquid low-level radioactive wastes (LLRW). Each RadAway cartridge contains a proprietary slurry that, according to the vendor, binds radioactive molecules thereby removing them from liquid waste. The technology reduces the volume of LLRW to be disposed of to one thirtieth the original volume. This volume reduction in turn greatly reduces the cost of disposal.

The vendor also claims that RadAway can effectively separate mixed waste—waste containing radioactive materials and hazardous solvents. This separation allows the solvent to be disposed of separately from the radioactive component, greatly reducing disposal costs. However, RadAway does not have regulatory approval for mixed waste.

RadAway will not produce excellent results (>90% binding) for lipids or solutions with visible suspended solids and is not recommended for scintillation fluids or solutions containing bleach.

As of late 1999, Naiad Technologies was closed for business.

Technology Cost
No available information.

T0544

National Renewable Energy Laboratory

Solar Detoxification of Water

Abstract
Researchers at the National Renewable Energy Laboratory (NREL) in cooperation with Sandia National Laboratories are exploring applications of solar detoxification to the remediation of contaminated groundwater. This technology is an adaption of photocatalytic destruction using ultraviolet lamps. In solar detoxification, a photocatalyst (titanium dioxide) is used that generates hydroxyl radicals at approximately ambient temperatures when exposed to near-ultraviolet light. These hydroxyl radicals react with organic contaminants to form carbon dioxide, water, and dilute concentrations of simple mineral acids (i.e., hydrochloric acid). Research indicates that titanium dioxide can also reduce metal ions in solution, in some cases forming insoluble metal hydroxides and salts. The technology is not currently commercially available.

Researchers claim the following advantages of solar detoxification:

- Destroys hazardous organic contaminants and can reduce some metals to insoluble compounds.
- Allows for on-site use and eliminates the need to transport wastes.
- Avoids air emissions associated with some treatment technologies and uses no fossil fuel energy during treatment.

Halide-saturated hydrocarbons such as carbon tetrachloride degrade very slowly, if at all, when exposed to solar detoxification treatment. Bicarbonate, a common constituent of groundwater, acts as a scavenger of hydroxyl radicals and can significantly hinder solar detoxification treatment. The presence of nontargeted contaminants in process influent can lower process efficiency.

Technology Cost

A cost analysis was performed in 1991 for a solar detoxification system at Livermore, California, capable of processing an average of 4.4 liters/sec of water with a peak flow of 30 liters/sec. The system would be processing water containing 400 parts per billion (ppb) trichloroethylene to a treated concentration of 5 ppb. Costs were estimated at \$16.00 per 1000 gal. Data from the field test using a one-sun mode of operation reduced the estimated cost to roughly \$7.00/gal (D12953N, p. 203).

A similar estimate at the Radian Corporation estimated costs at \$15.40 per 1000 gal. This estimate was higher than for alternative technologies: ultraviolet oxidation (\$4.00 per 1000 gal) and granular activated carbon treatment (\$5.00 per 1000 gal). It was predicted, however, that costs of solar detoxification could be lowered to \$3.00 per 1000 gal. The Radian study noted that costs at the Livermore site may be higher than for most applications of solar detoxification technology. It estimated the cost of conventional treatment would range from \$1.40 to \$3.00 per 1000 gal (D12953N, pp. 203).

Another 1991 cost estimate was performed by the Bechtel Corporation for the U.S. Department of Energy's (DOE's) Rocky Flats Plant near Boulder, Colorado. Costs were estimated at \$40 per 1000 gal for a system in a site with relatively low solar insolation. The estimate was based on a system with a peak water flow of 6.3 liters/sec and an annual treated volume of 8500 gal. The processing costs were dominated by the cost of a system to treat inorganic components of the water (D12953N, p. 203).

Sensitivity studies have shown that costs are likely to be contaminant specific and depend on plant size and location. The design of a commercial facility has not been finalized. Solar collectors are the largest cost component of solar detoxification systems, and some research indicates that a one-sun system (in a one-sun system, solar energy is not concentrated by reflectors or solar panels) that does not use a solar collector may be more efficient in accessing diffuse ultraviolet light. Another design concern that may impact process costs is the use of a fixed catalyst versus a slurry feed (D12953N, pp.190–203).

Information Source

D12953N, Blake et al., 1992

T0545

National Research Council of Canada

Solvent Extraction Soil Remediation (SESR)

Abstract

The Institute for Chemical Process and Environmental Technology (ICPET), which is a part of Canada's National Research Council, has developed a solvent extraction process called Solvent

Extraction Soil Remediation (SESR), in which the separation of fine particles from the extracting solvent is enhanced using a liquid-phase agglomeration technique. Liquid-phase agglomeration is a size enlargement technique that can be used as an aid to improve the separation of fine solids from either aqueous or organic based suspensions or slurries. Liquid-phase agglomeration techniques and solvent extraction occur concurrently. This technology is capable of remediating highly saline industrial soil contaminated with oil and heavy metals.

SESR is applicable for soils contaminated with petroleum hydrocarbons, polychlorinated biphenyls (PCBs), and pentachlorophenol (PCP). The technology has been demonstrated to fix heavy metals and remove hydrocarbon contaminants simultaneously. After treatment, soluble salts can be leached from the dried, agglomerated soil.

The primary application for this technology is the cleanup of heavily contaminated soils from abandoned herbicide and pesticide manufacturing sites and mixed petroleum wastes containing both hydrocarbon and heavy-metal contaminants. It also has potential as a remediation technique to restore fertility to agricultural soils suffering from overuse and salt buildup from irrigation.

This technology is at the bench scale and is not yet commercially available.

Technology Cost

According to the developer, a 5 ton per hour mobile plant could be designed and built for about $2.35 million (Canadian), plus or minus 25% (D17555X, p. 1; D17557Z, p. 1). In 1998, the vendor stated that operating costs for a 5 ton-per-hour plant would be from $30 to $35 (Canadian) per metric ton, excluding excavation and secondary stream costs. Total costs were estimated to be $140 (Canadian) per metric ton (personal communication, Abdul Majid, National Research Council of Canada, 1998).

In 1992, researchers developed an engineering and costing design for a fixed unit that operated at a rate of 2 tons per hour. Costs were estimated to be $149 (Canadian) per metric ton of soil treated. This estimate was based on the following assumptions: the unit used medium naphtha as a solvent; operations were 24 hours per day, for 260 days per year; utilization factor of the facility was 83%; capital costs were $2.548 million (Canadian); and capital amortized over 10 years at 10%, two payments per year. The estimate stipulated that the recovered oil was of suitable quality to be sold to offset process costs. It was estimated that the largest component of process costs would be labor ($56 per ton of waste treated). Other cost components listed were: capitalization costs ($38 per ton), utilities ($29 per ton), insurance ($9 per ton), trucking and maintenance (each $5 per ton), equipment rental and site excavation and restoration (each $3 per ton), and waste disposal was estimated to cost $1 per ton (D17896F, p. 8).

Information Sources

D17554W, Sparks, Meadus, and McNabb, 1992

D17555X, Sparks, 1998

D17557Z, Envirotech, 1997

D17896F, Sparks, Meadus, McNabb, 1992

T0546

Natural Attenuation — General

Abstract

Natural attenuation, often called intrinsic remediation, intrinsic bioremediation, bioattenuation, or monitored natural attenuation (MNA) is an in situ treatment technology for soil, sediment, or groundwater. The technology has been used for full-scale remediation of sites contaminated with volatile organic compounds (VOCs), total petroleum hydrocarbons (TPH), chlorinated solvents, explosives, inorganics, and metals.

Natural attenuation is defined by the U.S. Environmental Protection Agency's (EPA's) Office of Solid Waste and Emergency Response (OSWER) as follows:

> Natural attenuation refers to naturally-occurring processes in soil and groundwater that act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in those media. These in situ processes include biodegradation, dispersion, dilution, adsorption, volatilization, and chemical or biological stabilization or destruction of contaminants.

While the processes entailed in MNA take place without human intervention, the technology is not a "do-nothing" approach. Before MNA can be chosen as a site remedy, assessments are required to determine the risks at the site and to determine if MNA can be effective in reducing those risks to acceptable levels. Evaluations are required for factors that could influence natural attenuation processes over time. Also, long-term monitoring is required during MNA.

While natural attenuation will not be a suitable remedy for all contaminated sites, it does offer the following potential advantages:

- Generates less secondary wastes, reduced risk of exposure during treatment.
- Operates in situ with minimal site disturbance.
- Can be used in conjunction with other remediation technologies.
- Reduced need for on-site structures associated with cleanup.
- Potentially reduces overall remediation costs.

The potential limitations of natural attenuation include:

- Generally requires longer time frame for remediation.
- Requires more involved site characterization and monitoring.
- Toxicity and mobility of transformation products may be greater than that of the parent compound.
- Changes in environmental or site conditions may allow contaminant migration.
- Public may see natural attenuation as a "do-nothing" approach.

Technology Cost

There are several costs associated with the implementation of natural attenuation. The costs include modeling contaminant degradation rates to determine if natural attenuation is a feasible remedial alternative, subsurface sampling and sample analysis (potentially extensive) for determining the extent of contamination and confirming contaminant degradation rates and cleanup status. Regular operation and maintenance (O & M) costs are required for monitoring to verify degradation rates and maintain data on contaminant migration (D113291).

A site-specific, cost–benefit analysis is required to determine if an active remediation system or MNA would be the most effective remediation option (D11322U, p. 8). In 1999, the U.S. Army prepared an analysis of the cost of MNA, in situ bioremediation, and pump-and-treat systems for the treatment of explosives-contaminated groundwater at the Louisiana Army Ammunition Plant in Minden, Louisiana (D22026Y). This comparison is summarized in Table 1.

At the Sierra Army Depot in Herlong, California, groundwater had been contaminated by trinitrotoluene (TNT) and trichloroethylene (TCE). The 28-acre plume of contaminated groundwater was located about 70 ft underground. The U.S. Army evaluated the cost difference between conventional pump-and-treat systems, ultraviolet (UV) oxidation, granular activated carbon (GAC) filters, and MNA. The active treatments were estimated to cost between \$6 and \$10 million while MNA costs were estimated to be approximately \$1 million (D17451Q).

At a U.S. Air Force site in south central California, the cost for implementation of MNA was estimated to be \$4 million. The least costly alternative remedial option (in situ air sparging/soil

TABLE 1 Cost Comparison (in dollars) of Treatment Options for the Louisiana Army Ammunition Plant, Minden, Louisiana[a]

Cost Item	Monitored Natural Attenuation	In Situ Bioremediation	Pump-and-Treat/ Activated Carbon Adsorption
	Pretreatment Costs		
Mobilization, preparatory work	164,600	34,600	34,600
Monitoring, sampling, testing, analysis	566,000	36,000	36,000
Site work	187,260	257,390	309,360
Solids collection and containment	12,000	12,000	12,000
Liquids collection and containment	7,000	5,000	5,000
	Treatment Costs		
Total estimated treatment costs	2,148,000	3,679,150	5,542,500
	Closure Costs		
Demobilization	120,000	145,600	145,600
Site restoration	40,000	40,000	40,000
Total	3,244,860	4,209,740	6,125,060

Source: Adapted from D22026Y.
[a]Cost estimate assumes a 25-acre site equally suitable for the application of any of the three technologies and 20 years for achievement of cleanup goals.

vapor extraction) was estimated to cost approximately $14.4 million and did not provide any additional benefit (D169602, p. 8).

Maryland Superfund Site Natural attenuation enabled new development at 70-acre Superfund site approximately 20 miles northwest of Baltimore, Maryland. This property had been contaminated by a printed circuit board manufacturing company. According to a manager, the pump-and-treat remediation system failed to meet groundwater treatment goals, though it cost over $1 million to construct and more than $200,000 a year to operate. It was estimated that this approach could cost as much as $5 million over 10 years and would still not achieve the cleanup objectives of the Maryland Department of Environment (D17452R).

Treatability studies indicated that MNA could address the contamination at the Maryland site. To eliminate all current and future risks, the municipal water supply was extended to the site. Since the contaminated groundwater on-site was no longer used for drinking water, the property was able to be sold for commercial and residential development. MNA costs were $1 million (D17452R).

Information Sources

D113291, Remediation Technologies Screening Matrix, 1996

D11322U, Ritz, 1996

D169602, Malloy et al., 1996

D17451Q, Buckley, 1996

D17452R, Asmus, 1997

D22026Y, Pennington et al., 1999

T0547

NEPCCO Environmental Systems

SoilPurge

Abstract
NEPCCO SoilPurge™ soil vapor extraction systems are noncontacting, oil-free, explosion-proof vacuum systems designed to remove volatile organic compounds (VOCs) from soil in situ. According to the vendor, benzene, toluene, ethylbenzene, and xylenes (BTEX), chlorinated solvents and other hydrocarbons can be treated with SoilPurge systems. The technology can also remove radon from soil.

The SoilPurge technology is currently commercially available.

According to the vendor, the SoilPurge soil vapor extraction systems are constructed for one-person installation, are skid mounted, have a total height of less than 4 ft, and are available in footprints starting at 36 inches by 30 inches.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0548

NEPCCO Environmental Systems

SpargePurge

Abstract
NEPCCO Environmental Systems has developed the SpargePurge™ system for the in situ treatment of volatile organic compounds (VOCs) in soil or groundwater. The system can operate by itself or as part of an integrated system with another NEPCCO technology, SoilPurge™.

The vendor claims the technology is easily portable, can be integrated with other systems, and can operate over a wider variety of air sparging conditions.

All information included in this summary was provided by the vendor and has not been independently verified.

Technology Cost
No available information.

T0549

NEPCCO Environmental Systems

TurboTray™ Air Stripper

Abstract
The TurboTray™ is an air stripper for the removal of volatile organic contaminants (VOCs) from water. The TurboTray line of air strippers is commercially available, and NEPCCO has “fielded” hundreds of one- and two-piece units.

The air strippers are fabricated from fiber-reinforced plastic and stand up to 9 ft tall. The TurboTray brings water into contact with a large volume of air inside a chamber, causing the VOC to undergo a phase change from liquid phase to vapor phase. This results in the majority of the VOCs being transferred to the discharge airstream while the treated water is discharged at the bottom of the air stripper.

All information was provided by the vendor and could not be independently verified.

Technology Cost
No available information.

T0550

NEPCCO Environmental Systems

TurbOzone

Abstract
TurbOzone™ is a commercially available, ex situ technology that uses ozone gas to treat cooling tower water. According to the vendor, TurbOzone systems are capable of treating cooling towers from 150 to 2000 tons.

The vendor claims that TurbOzone has the following advantages: it eliminates the purchase, handling, storage and discharge of chemicals; it conserves water through reduced blowdown; it reduces or eliminates scale formation; a superior biocidal control eliminates biofilm in system piping and condenser tubing; it enhances cooling system performance and reduces operating costs. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0551

NEPCCO Environmental Systems

VaporPurge

Abstract
The VaporPurge system is a turnkey skid-mounted vapor treatment system product line consisting of a vacuum-enhanced pumping system; a thermal catalytic oxidation system; and a vapor-phase carbon adsorption system. The vacuum-enhanced pumping system removes groundwater from wells as well as volatile organic chemicals (VOCs) from soil. This dewaters extraction wells and creates air movement through soils. After air and water are separated, they may be treated by conventional remediation methods. The thermal oxidation system treats VOC vapors from air strippers and soil vapor extraction systems. The vapor-phase carbon adsorption system uses granulated activated carbon (GAC) adsorbers to treat air contaminated with organics.

The system is commercially available through the vendor. All information is provided by the vendor and has not been independently verified.

Technology Cost
No available information

T0552

NEPCCO Environmental Systems

Photocatalytic Oxidation Technology

Abstract

Photocatalytic oxidation (PCO) is a destructive process for the treatment of gas-phase waste streams that can operate successfully at low concentrations of contaminants and at a low energy cost. In this technology, ultraviolet (UV) light illuminates a titanium dioxide catalytic surface at room temperatures and produces hydroxyl radicals, which destroy volatile organic compounds (VOC's).

Potential applications include treating VOC-contaminated airstreams from air-stripping, industrial air emissions, and cleaning air in closed environments. PCO is best suited for treating waste streams with low concentrations of contaminants and with low to medium flow rates. The technology is commercially available.

Laboratory tests show that the technology is applicable to chlorinated solvents such as trichloroethylene (TCE) and tetrachloroethylene (PCE); acetone; benzene; methyltentbutyl ether (MTBE); alcohols; and other common solvents.

PCO has the following advantages over conventional treatments:

- Significant reaction rates occur at or near room temperature.
- It is extremely energy efficient.
- It is relatively inexpensive and does not require reloading with expensive metal.
- The catalyst does not foul readily.
- An oxidizing agent, such as hydrogen peroxide, is not required.
- Treats a broad range of organic compounds.

The PCO system operates most efficiently on a small scale with low contaminant concentrations and variability, low relative humidity, long residence times in the reactor, high UV light intensity, and higher temperatures.

Technology Cost

At the March Air Force Base in Riverside, California, the total cost to remediate 292,000 ft^3 of contaminated air using a PCO system was $39,000 (D10303N, pp. 9, 10).

The capital cost for a NEPCCO Environmental Systems (formerly known as Zentox Corporation) PCO system capable of processing 18 standard cubic meters of contaminated air per minute was $175,000 to $260,000 (D19079Y, p. ES-8).

Costs have been estimated for the general class of PCO technologies. The cost of the PCO technology is dependent on a number of variables. These include photoefficiency, ultraviolet intensity, contaminant concentration, and the desired level of destruction of contaminants. The costs for air pollution control equipment are typically given as dollars per cubic feet per minute (cfm).

In 1994, the National Renewable Energy Laboratory [NREL, a national laboratory of the U.S. Department of Energy (DOE)] performed a cost comparison of PCO versus other air pollution control technologies. It was determined from this study that the cost per cubic feet per minute increased with contaminant concentration, but fluctuated little with flow rate. For VOC concentrations above 1000 parts per million (ppm), the PCO system was expensive relative to other technologies (D130905, p. 3).

The capital costs of a PCO system are similar or slightly higher than competing technologies, but the operating costs are the lowest for the technologies studied by NREL. Capital costs for

TABLE 1 PCO Cost Estimates from a Study Performed by the Los Alamos National Laboratory

Flow Rate	100 cfm		500 cfm	
Influent Concentration	50 ppm	1,000 ppm	50 ppm	1,000 ppm
Equipment Cost	$33,922	$52,722	$89,095	$138,476
Capital Cost	$78,549	$102,989	$149,118	$212,819
Operation & Maintenance Cost	$21,800	$21,800	$21,800	$21,800

Source: Adapted from D12104Q, pp. 59, 60.

a PCO system range from $60 to $320/cfm. Annual operating costs vary from $5 to $90/cfm. The levelized annual cost is estimated between $15 and $140/cfm (D130905, Table 2).

In 1996, the DOE Los Alamos National Laboratory had similar observations, noting that while capital costs rise slowly, as contaminant concentration increases, the cost of materials, operation and maintenance, and labor remains constant (D12104Q, p. 59). Refer to Table 1 for results from the Los Alamos cost analysis.

The PCO system can operate basically unattended, resulting in extremely low operation and maintenance costs (D12104Q, p. 25). Over a 10-year life cycle, the Los Alamos National Laboratory estimates that operating costs will make up only 17% of total costs. Capital costs account for 43%, utilities for 14%, and maintenance for 26% of the total costs (D12104Q, p. 26).

Information Sources

D10303N, VISITT, date unknown
D12104Q, Cummings and Booth, 1996
D130905, Turchi et al., 1994
D19079Y, U.S. EPA, 1998

T0553

New Jersey Institute of Technology

Ultrasound-Enhanced Soil Washing

Abstract
Ultrasound-enhanced soil washing is an ex situ process being researched for use in soil washing remediation. The technology is not yet commercially available.

The application of ultrasonic energy creates acoustic cavitation, resulting in shear forces intended to remove contaminants adhering to soil particles.

According to the New Jersey Institute of Technology, results of research to date are preliminary and may not accurately reflect the final results to be published at a later date.

Technology Cost
No available information.

T0554

New Mexico Institute of Mining and Technology

Surfactant-Modified Zeolite

Abstract
The New Mexico Institute of Mining and Technology has developed surfactant-modified zeolite (SMZ) technology for use as an in situ permeable barrier to remove organic and inorganic

contaminants from contaminated groundwater. Zeolites are naturally occurring hydrous silicate minerals typically formed in association with lava flows. They possess a cagelike structure with a high surface area and have been used commercially for their ion exchange capability.

Researchers found that zeolite particles can be treated with high-molecular-weight surfactants [such as hexadecyltrimethylammonium (HDTMA)]. HDTMA does not penetrate into the internal pore structure of the zeolite, but coats the outer surface. The outer surface then develops hydrophobic anionic exchange properties, while the inner surface retains the capacity to adsorb cations. Researchers claim that SMZ can be used for the three major classes of water contaminants: inorganic cations, inorganic anions, and nonpolar organics.

SMZ has been through proof-of-concept testing, and a pilot-scale test of the technology has been completed. The technology is not currently commercially available.

Researchers state that modified zeolite has the following potential advantages:

- Provides an economical method for limiting the migration of groundwater contamination.
- Offers the ability to selectively adsorb both negatively charged and positively charged ionic contaminants.
- Allows other remediation technologies (e.g., bioremediation and air stripping) to be focused within the barrier rather than on the entire contaminated aquifer.
- Uses commercially available slurry wall technology for barrier installation.

During pilot-scale testing of SMZ with zero-valent iron, the treatment pellets had an insufficient coating of surfactant. As a result, chromate reductions were lower than expected. Researchers note that additional work is needed to ensure that the pellets are sufficiently coated during bulk production. In addition, SMZ adsorption of chromate ions may be limited in the presence of competing anionic substances, such as sulfate. Because the technology is just advancing beyond the proof-of-concept stage, limited peer-reviewed information is available.

Technology Cost

Researchers estimate that the material costs for SMZ will range between \$350 and \$400 per ton. This estimate assumes that zeolite will cost between \$60 and \$100 per ton and that the HDTMA surfactant will cost \$3.65/lb. The cost of combining the zeolite and the HDTMA is considered to be no more than 20% of the materials cost. Thus, the cost of producing SMZ for installation in a permeable barrier will be approximately \$500 per ton. This cost translates to roughly \$10 to \$15/ft^3 of SMZ (D15585V, p. 36). According to researchers, SMZ has already been produced in bulk quantities (20 tons) at a cost of \$400 to \$450 per ton, or \$12/ft^3 (D22694S, p. 1). Researchers claim that the technology should be less expensive than activated carbon, ion exchange resins, or zero-valent iron (competing permeable barrier technologies) (D15585V, p. 36).

A pilot-scale study of a barrier containing SMZ was conducted at Oregon Graduate Institute, in Beaverton, Oregon. The barrier, which was 20 ft long, 3 ft thick, and 6.5 ft deep, contained 12 tons of reactive media. The design cost for the barrier was \$75,000. Barrier installation costs were \$25,000, including expenses associated with construction, materials, and reactive media (D206053, p. 1).

Based on 1997 data, the estimated cost of a permeable reactive barrier (PRB) system ranged from approximately \$405,000 (corresponding to \$1400 per 1000 gal of groundwater extracted) to \$585,000 (corresponding to \$225 per 1000 gal of groundwater extracted). The capital costs ranged from \$373,000 to \$500,000, and operation and maintenance (O & M) costs ranged from \$32,000 to \$85,000. Treatment wall costs included system construction, installation, monitoring, and analytical costs. Costs may vary due to differences in the subsurface matrix, thickness, and composition of wall. Data were provided by Geomatrix, the U.S. Navy, and the U.S. Coast Guard (D18882D, pp. 133, 145).

Information Sources

D15585V, Bowman, undated
D18882D, Federal Remediation Technologies Roundtable, 1998
D206053, U.S. EPA, undated
D22694S, Bowman et al., 1997

T0555

Niaski Environmental, Inc.

BioPurge

Abstract
BioPurge^{SM} is a closed-loop, in situ and ex situ bioremediation technology that uses vapor extraction, gas injection, and biodegradation to remediate contaminant plumes above the groundwater level. This process works by extracting soil vapor from wells placed at the perimeter of the contaminated area. Contaminated vapor passes through an ex situ biological treatment unit, where high concentration volatiles are absorbed and biologically degraded. The scrubbed vapor is enriched with oxygen and moisture, heated and reinjected at or below the groundwater level and/or within the contaminant plume. The enriched vapor then induces indigenous microbes to destroy soil contaminants.

The vendor claims that BioPurge can be effective in cleaning soils contaminated with petroleum hydrocarbons, chlorinated solvents, wood preservatives, and volatile organic compounds (VOCs). BioPurge is no longer commercially available.

The vendor claims that BioPurge has the advantages of being relatively inexpensive, controlling plume migration, creating no air emissions and no waste disposal. Also, compared to other bioremediation technologies, BioPurge performs relatively quickly.

Technology Cost
The vendor of this technology claims the approximate cost of remediation using the BioPurge and BioSparge^{SM} systems is \$20 to \$50/yd^3. This estimate may not include indirect costs associated with treatment (D12584I, p. 533).

The vendor claims the above cost is an approximate range. Actual costs will vary from site to site depending upon such variables as contaminant type and concentration and soil type (personal communication: Dr. Roy Crowther, Enviro FX, November 1997).

Information Source

D12584I, Burke et al., 1995

T0556

Niaski Environmental, Inc.

BioSparge

Abstract
BioSparge^{SM} is a closed-loop, in situ and ex situ bioremediation technology that uses vapor extraction, gas injection and biodegradation to remediate contaminant plumes below the groundwater level. This process works by extracting soil vapor from wells placed at the perimeter of

the contaminated area. Contaminated vapor passes through an ex situ treatment unit, where high concentration volatiles are absorbed and biologically degraded. The scrubbed vapor is enriched with oxygen and moisture, heated and reinjected at or below the groundwater level and/or within the contaminant plume. The enriched vapor then induces indigenous microbes to destroy soil contaminants.

BioSparge can be effective in cleaning soils contaminated with petroleum hydrocarbons, chlorinated solvents, wood preservatives, and volatile organic compounds (VOCs). BioSparge is not commercially available.

BioSparge has the advantages of being relatively inexpensive, controlling plume migration, creating no air emissions and no waste disposal.

BioSparge is typically ineffective in silts and clays where the porosity and permeability are low. Also, remediation of certain semivolatile compounds, including chlorinated solvents, requires that the system be modified by the addition of an ozone generator. The ozone reacts with the chlorinated compounds to produce by-products that can be biodegraded.

Technology Cost

The vendor of this technology claims the approximate cost of remediation using the BioSparge system is \$20 to \$50/yd^3. These estimates may not include indirect costs associated with treatment (D12584I, p. 533).

The vendor claims the above cost is an approximate range. Actual costs will vary from site to site depending upon such variables as contaminant type and concentration and soil type (personal communication: Dr. Roy Crowther, Enviro FX, November 1997).

Information Sources

D12584I, Burke et al., 1995

T0557

NoChar, Inc.

Leadbond

Abstract

Leadbond is an adsorption technology designed to remove heavy metals, particularly lead, from aqueous streams. This technology is typically used for purification of drinking water to remove lead contamination. The vendor states that it is also useful for the treatment of contaminated waste streams where lead removal is essential and where disposal is costly. Leadbond was developed by NoChar, Inc., and is commercially available.

All information is from the vendor and has not been independently verified.

Technology Cost

No available information.

T0558

NoChar, Inc.

Petro Bond

Abstract

NoChar's Petro Bond coagulants are designed to immobilize petroleum-based liquid and solvent spills through coagulation and bonding of the liquid. The Petro Bond product line consists of

A610, which is designed to solidify water-borne petroleum-based spills; A650, which is designed to congeal and bond water-borne petroleum-based spills; and A640R, which is designed to coagulate and extinguish land-based petroleum spills.

Petro Bond is commercially available through a number of vendors, including Environmental Management Consultants of Cicero, Indiana, and the Chamberlain Group, Ltd., of Lynchburg, Virginia.

According to a supplier of Petro Bond products, the technology has the following advantages:

- Operates as a single-step process.
- Uses a safe product that is nontoxic and can be incinerated.
- Minimizes processing time.
- Achieves an absorbent capacity of up to 15:1.
- Allows for easy disposal of solidified product.

Petro Bond is not suitable for some acids. The volatility of the treated material will vary depending on the contaminant treated. The vendor states that extreme care must be taken when handling, storing, or disposing of solidified or gelled hazardous materials.

Technology Cost

According to the vendor, Petro Bond costs less than comparable remediation technologies due to the following factors:

- Petro Bond has a greater absorption capacity than competing products.
- Solidification occurs within seconds after contact with the spill.
- Decreased disposal and labor costs reduce total remediation costs (D16468V, p. 2).

Table 1 gives the vendor's comparison of the Petro Bond technology and Floor Dry (a competing product). Table 2 gives the vendor's comparison of Petro Bond and polypropylene in treating a 100-gal spill.

TABLE 1 Vendor-Supplied Cost Comparison on Spill Cleanup of Diesel Fuel[a]

Parameter	NoChar A610	Floor-Dry
Weight of diesel	329.85 lb	329.85 lb
Minimum product/unit ratios	15/1	1/1
Product weight	21.99 lb	329.85 lb
Total spill weight	351.84 lb	629.70 lb
Number of 55-gal drums	1	1.88
Weight of drums	20.0 lb	37.5 lb
Total disposal weight	371.84 lb	697.20 lb
Disposal cost	$446.21	$836.64
Product cost	$317.54	$49.48
Additional labor cost	$0.00	$50.00
Total cost	$763.75	$936.12

Source: D16468V, vendor information.

[a] Assumptions: NoChar A610 cost: (2 pallets) $14.44/lb (40#) is $16.44/pound. Floor-Dry cost: $0.15/lb. Diesel fuel weight: 7.33 lb/gal. Disposal cost: $1.20/lb.

TABLE 2 Vendor-Supplied Diesel Fuel Cost Comparison

Parameters	NoChar's A610	Polypropylene
	49 lb of A610 at $12.00/lb	$73 single pads, 200 pads per 25-gal bail; 4 bails at $73 each to pick up 100 gal
Product	Total cost: $588	Total cost: $292
Waste generated	Two 55-gal drums	Three to four 55-gal drums
Disposal cost[a]	$500	$750–$1000
Labor cost[b]	$200	$500
Total cost	$1288	$1792

Source: D16468V, vendor information.
[a] Disposal cost = $250 per drum.
[b] Labor cost = $200 per hour.

Petro Bond is also available in pillows, socks, and booms. The price of these materials will vary according to the technology vendor, but 1997 cost data is supplied in Document D16468V (p. 3). The vendor has provided disposal cost estimates for oils spills absorbed using several commercially available technologies in D22716H.

Information Sources

D16468V, vendor information, undated
D22716H, vendor information, 2001

T0559

NORIT N.V.

Porta-PAC

Abstract
The NORIT Porta-Powdered Activated Carbon (Porta-PAC) dry injection system pneumatically conveys an adjustable amount of powdered activated carbon (PAC) from bulk bags into the flue gas streams of incinerators for mercury and dioxin emission reductions. PAC is metered using a volumetric feeder into a pneumatic eductor where moving air transfers the carbon to the injection point. A series of interlocks control the operation of the unit and allow local or remote operation and monitoring of the unit. This technology is commercially available. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0560

Normrock Industries, Inc.

Amphibex Excavator

Abstract
Normrock Industries, Inc., has developed the Amphibex amphibious excavator. The system can be used to remove contaminated debris and sediment from river beds and lakes. Amphibex

systems can “crawl” along the ground and only require a water depth of 45 cm to float. The system can be equipped with a variety of tool-arms, including a bucket for mechanical dredging, a rake for debris removal, a jackhammer to break large objects, and extension arms for excavation of sediment and debris in water greater than 6 m deep. The technology has been used in full-scale demonstrations and is commercially available.

The following advantages are claimed for the Amphibex system:

- Can be brought to the site via overland transport, and access to water bodies does not require a wharf.
- Can be used for many divers activities, including dredging, habitat creation, vegetation control, ice-breaking, and pipeline installation.
- Is effective in shallow water.
- Designed to minimize disturbances to surrounding sediments during dredging activities.

Any dredging process necessarily disturbs the marine environment and results in a certain degree of sediment resuspension. Contaminated sediments removed by the Amphibex unit will require storage and recovery before treatment with a remediation technology. The removal rate can be significantly reduced by the presence of large debris such as logs, bicycles, boat anchors, and large rocks. The removal of gravel can lead to erosion of process machinery.

Technology Cost

In 1998, an estimate was prepared for the cost (in U.S. dollars) of the Amphibex excavator system. According to information provided by the vendor, the cost quotation standard for dredging 20,000 m^3 of sediment ranged from \$6.50/m^3 for uncontaminated silt, to as much as \$22/m^3 for excavation of contaminated clay. Average costs were listed as \$9/m^3 of uncontaminated silt and \$17/m^3 of contaminated clay excavated. Costs were stated to be site specific and dependent on the users requirements. The capital costs (dredging only) associated with uncontaminated silt processing ranged from \$100,000 to \$200,000, and capital costs (dredging only) associated with contaminated clay ranged from \$300,000 to \$400,000 (D18701T, pp. 1–2).

Also in 1995, the Amphibex was selected to help construct a flow-balancing system in Bluffer’s Park, Scarborough, Ontario, Canada. Material removed at the site was not treated for any contamination. The removal rate was significantly reduced by the presence of large debris such as logs, bicycles, boat anchors, and large rocks. The total cost of mobilizing, dredging, trucks loading, and demobilization was \$320,128 (U.S.) for a unit cost of \$9.15 (U.S.) per cubic meter, (D18701T, pp. 16, 17).

It was reported by Enviroaccess in 1996 that the purchase of an Amphibex excavator required a total investment of between \$395,000 and \$450,000, depending on the tools needed. It was not specified whether this amount was listed in Canadian or U.S. dollars. Operating costs, calculated on an annual basis of 2000 hr of work, are about \$80/hr. This amount does not include personnel costs (operators and labor) but does take into account annual depreciation of the machine, insurance, routine maintenance, fuel costs, and normal wear and tear (D18700S, p. 2).

Information Sources

D18701T, Globaltechs, 1998 web page

D18700S, Enviroaccess, 1996 web page

T0561

North American Drilling Technologies, Inc. (NADT)

EnviroZyme System

Abstract

The EnviroZyme™ System (EZS) is a proprietary, commercially available technology for the ex situ treatment of soils, sludges, or wastes contaminated with petroleum hydrocarbons

and/or chlorides. EZS uses a catalytic enzyme solution and a continuous-flow mechanical shear to reduce contaminants. According to the vendor, the technology successfully reduces total petroleum hydrocarbons (TPH), benzene, toluene, ethylbenzene, and xylenes (BTEX), and total chlorides below regulatory requirements at refineries, oil storage facilities, and exploration and production (E & P) sites.

The vendor claims the enzyme solution is produced through a biological process and is nonhazardous. Enzyme solution is reused until the end of the project, when it can be injected into a nonhazardous waste disposal well or processed through a wastewater treatment facility.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0562

North American Technologies Group, Inc.

System IV

Abstract
System IV is a pretreatment technology for water containing cyanide and heavy metals including chromium, nickel, zinc, lead, cadmium, and copper. The technology precipitates a range of heavy metals; there is no need to install separate pieces of equipment for individual metals. A cyanide treatment system expansion option is available for waste streams that also contain cyanide. System IV is not offered commercially.

The vendor claims that System IV treatment has the following advantages:

- Remediation of groundwater containing soluble metals such as chromium,
- Chromium VI reduction and heavy-metal precipitation in one reaction,
- The effluent exceeds Clean Water Act pretreatment standards,
- Significantly reduced initial capital equipment costs,
- Process is odorless,
- Process does not generate toxic or corrosive gases.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0563

North American Technologies Group/InPlant, Inc.

SFC Oleofiltration System

Abstract
The SFC Oleofiltration system separates hydrocarbons from water. The technology combines a vertical-fin coalescing unit and a patented, amine-coated, oleophilic granule filtration system (the Oleofilter) into one system that can, according to the vendor, separate mechanical emulsions of hydrocarbons in water that are not treatable by conventional oil/water separators. The Oleofilter can also separate many chemical emulsions and reduce the concentrations of dissolved hydrocarbons. The technology is not commercially available.

According to the vendor, the technology can effectively treat almost all hydrocarbons (including gasoline, crude oil, diesel fuel, and jet fuel), pentachlorophenols, polychlorinated biphenyls, benzene, toluene, ethyl benzene, xylene, polynuclear aromatic hydrocarbons, trichloroethylene, trichloroethane, and suspended solids. The granules can also be used to remove vegetable-based oils and fats. Another technology advantage is the ability of the SFC system to remove oil emulsified in water to concentrations less than 15 mg/liter.

Operation at pH greater than 10.5 lowers the treatment life of the oleophilic granules. Effluent may require additional treatment prior to disposal. Even under ideal conditions, the treated water effluent will still contain between 5 and 15 mg/liter of total petroleum hydrocarbons (TPH), which may require additional treatment prior to disposal.

Technology Cost

In 1995, as part of the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration, a cost estimate of SFC Oleofiltration technology (the SFC system) was performed. The estimate stated that the cost of processing 50 million gallons of waste with the SFC-8 system operating at 22 gal/min with a 95% online factor was \$2.36 per 1000 gal of waste treated (D11018P, p. 14). A summary of the estimate is given in Table 1, along with estimates for a 90% online factor, and for a 99% online factor.

For the above estimate, total equipment costs for the SFC system was estimated at \$35,540. This included the vertical fin coalescing unit, oleophilic ceramic granules, pumps, a pneumatic control system, and such ancillary equipment as a 2000-gal bulk tank with fittings, a skimmer, necessary switches, valves, piping, and wires (D11018P, p. 28).

For a 1993 study of SFC system applications for treating drain water with an inlet flow of 240 m^3/day, and an inlet concentration of 30 parts per million (ppm) total petroleum hydrocarbons, the vendor estimated costs at \$0.13/m^3 of wastewater treated. The vendor states this cost would be significantly lower than activated carbon treatment of the same waste stream (D11018P, p. 59).

TABLE 1 Treatment Costs in Dollars per 1000 gal for the SFC 8 System Treating 50 Million Gallons of Contaminated GroundWater

Cost Item	90% Online Factor	95% Online Factor	99% Online Factor
Site preparation	0.02	0.02	0.02
Equipment[a]	0.51	0.48	0.46
Permitting and regulatory	NE[b]	NE	NE
Startup and fixed	0.73	0.72	0.70
Labor	0.24	0.23	0.22
Supplies	0.32	0.32	0.32
Consumables	0.32	0.32	0.32
Effluent treatment and disposal	NE	NE	NE
Residuals	NE	NE	NE
Waste handling, shipping, and transport	NE	NE	NE
Analytical	NE	NE	NE
Facility modification, repair, and replacement	0.25	0.23	0.22
Site demobilization	0.04	0.04	0.04
Total operating costs	2.43	2.36	2.30

Source: Adapted from D11018P.
[a]Includes salvage value of granules.
[b]NE, not estimated in this analysis.

Information Source

D11018P, U.S. EPA, 1995

T0564

North East Environmental Products, Inc.

ShallowTray Air Stripper

Abstract
ShallowTray® air strippers are low-profile, transportable units for removal of volatile contaminants from aqueous waste streams and potable water supplies. Air strippers do not destroy contaminants but transfer them to the airstream, where they can be destroyed by incineration or oxidation, removed by activated carbon, or released into the atmosphere if relevant emissions criteria are met.

The ShallowTray air stripper is protected under U.S. Patents 5,045,215 and 5,240,595. ShallowTray is a registered trademark of North East Environmental Products, Inc. The technology has been applied at full-scale remediation projects and is commercially available.

According to the vendor, ShallowTray systems provide a fast, efficient approach to removing volatile organic compounds (VOCs) from contaminated groundwater and process water. They operate at very high water-to-air ratios, allowing for greater removal of "difficult to strip" contaminants. Systems can be operated at variable flow rates and allow for easier removal of scale and fouling agents.

Waste streams with high concentrations of heavier fuel oils, such as kerosene or transformer oils, are more difficult to treat with this system (D17046H, p. 5). Pretreatment may be necessary, as may treatment of the effluent streams created during treatment.

Technology Cost
ShallowTray low-profile air strippers range in capacity from 0.5 to 550 gallons per minute (gpm) and in cost from $2500 to $150,000. Each system is custom designed and applied to suit the type of contaminants and desired treatment flow (personal communication, Barry Clarke, NEEP, Inc., 9/97).

According to the vendor, systems designed for flow rates ranging from 1 to 12 gpm list from between $5428 and $11,260. Systems designed to operate from 1 to 25 gpm list from $7148 to $14,463. Systems designed with a maximum flow rate of 50 gpm list from $10,431 to $19,850; while those with a maximum capacity of 75 gpm list from $14,805 to $24,810. A ShallowTray unit with a maximum capacity of 150 gpm lists from $22,620 to $37,720; while those designed to operate at flow rates of up to 200 gpm can list up to $56,791. Price quotes can be provided for larger capacity systems. Systems are normally built according to client specifications, so these prices are intended to serve as guidelines only (D19061O, p. 2).

Information Source

D19061O, vendor literature

T0565

Northern Watertek Corporation

Atomizing Freeze Crystallization (AFC)–Snowfluent

Abstract
The Atomizing Freeze Crystallization™ (AFC)–Snowfluent™ technology is specifically designed for cold climates. The technology combines freeze crystallization and snow-making techniques

to treat wastewater from industrial, food, agricultural, and mining processes; landfill leachate; and municipal sewage. When the wastewater spray enters the cold air, dissolved carbon dioxide gas is stripped away, raising the pH of the water. This in turn converts ammonium ion to ammonia, which also escapes as a gas. During the process of freezing, other contaminants physically separate from the water but remain trapped within the center of the frozen droplet. Bacterial contaminants are also killed by the freezing process. Although it is ideally suited for colder climates, the technology can be integrated with warm weather processes, such as sand filtration or spray irrigation, to provide year-round treatment.

The AFC–Snowfluent technology was developed with the aid of the Ontario Ministry of the Environment and Energy (MOEE), is patented, and is commercially available.

The vendor claims the following advantages to AFC–Snowfluent technology:

- Suitable for zero-discharge options.
- Functions in cold climates where many other technologies either fail or suffer from reduced effectiveness.
- No requirement for floccing to remove suspended solids.
- Eliminates bacteria without requiring chemical disinfectants.
- Higher pH of meltwater may act to lessen the effects of acid rain and snow.
- Operates as a batch process; does not need a continuous wastewater flow.
- Snow deposit land can be used for revenue-generating agricultural purposes.
- Low cost of operation.

The technology is best suited for cold winter temperatures and must be combined with other remediation technologies for warm weather treatment. Acreage is required for the storage of the man-made snow.

Technology Cost

According to the vendor, construction costs for AFC–Snowfluent plants are up to 74% of the cost of secondary treatment systems and up to 50% of the cost of tertiary plants. When Snowfluent is combined with warm weather technologies, capital costs are approximately 55 and 30% of comparatively equipped secondary and tertiary treatment plants, respectively (D15534K, p. 13). Comparative operating costs are outlined in Table 1. Operation in freezing conditions eliminates the energy required to freeze water droplets. Nighttime operation further reduces costs since electric utility rates are lower at this time (D15534K, p. 5).

Northern Watertek Corporation installed an AFC–Snowfluent system for the Carrabassett Valley Sanitary District in Maine. The full-scale system acts as a secondary treatment for the district's sewage. The 600-gal/min system cost $850,000 (D21581G, p. 2; D20590D, p. 2).

In Westport, Ontario, Canada, a $2 million AFC–Snowfluent plant was installed to treat 30 million gallons of sewage per year. The treatment costs for the plant are approximately

TABLE 1 Comparative Operating Costs of Snowfluent versus Secondary and Tertiary Treatment of Wastewaters

Technology	Cost per Cubic Meter	Cost per 1000 U.S. Gallons
Snowfluent	$0.10–$0.24	$0.40–$0.90
Secondary treatment	$0.46–$1.08	$1.75–$3.50
Tertiary treatment	$1.08–$1.45	$3.50–$5.50

Source: D15534K, Delta Engineering.

$0.80 per 1000 gal of influent wastewater. Each year, the plant costs the town approximately $100,000 (D21579M; D21581G, p. 2).

Hog Manure Treatment As part of a project to determine the suitability of AFC–Snowfluent technology to raw liquid hog manure waste, the technology was compared to two established control methods—surface application and direct injection. For the purposes of the estimate, it was assumed that the site in question had a lagoon with a capacity of 1.5 million gallons and a total manure production of 2.8 million gallons per year. This necessitates that the lagoon be emptied twice a year. It was noted that both surface application and direct injection methods generate intense odors. It was estimated that the cost of a surface application of hog manure was $25,748.00 to spread and incorporate the manure. Direct injection was estimated to cost $26,705.00 (D176823, p. 20).

The vendor charges $1.60/m^3 to convert hog manure to snow. To process the 2.8 million gallons of waste would cost $20,366.40. This cost does not include the value of nitrogen or other crop nutrients lost during processing. In periods with higher risk for warm temperatures, the vendor charges $2.00/m^3 of waste treated. This would increase the base cost to $25,458.00. The process leaves a residue containing approximately 50% organic material that must be spread. In a worst-case scenario, with a projected 100% loss of the nitrogen content from the raw liquid manure, the total cost of the AFC–Snowfluent technology would be $28,963.40 (D176823, p. 20).

Information Sources

D15534K, Delta Engineering

D176823, Alberta Research Council, 1998

D20590D, Gibson, 1996

D21579M, Community Press Online, undated

D21581G, Dumesnil, 1997

T0566

NUCON International, Inc.

BRAYCYCLE/BRAYSORB

Abstract

A technology based on the Brayton refrigeration cycle is commercially available for solvent recovery from off-gases and air pollution control. The Brayton cycle can be used to cool process streams to directly recover solvent or to regenerate activated carbon beds that absorb the solvents. This process can be effectively applied at both high and low concentrations. BRAYCYCLE® is the term used to describe the straight condensation process used at high concentrations of solvents. For low concentrations, activated carbon beds are used to concentrate volatile organic compounds (VOCs) from airstreams. When the beds are saturated, they have reached a higher concentration that enables them to be regenerated with the Brayton cycle to remove contaminants. This process is termed BRAYSORB.

The commercially available technology is effective at recovering acetone, benzene, xylene, cyclohexanone, methylene chloride, and paraffinic and aromatic hydrocarbons. The Brayton technology can be used to treat industry airstreams including chemical, refining, coating and lining, petrochemical, adhesives, and magnetic tape.

Technology Cost

According to the vendor, the cost of this technology ranges between $600,000 and $4,000,000 depending on parameters such as the flow rate and the solvent to be recovered (personal communication, Jack Jacox, NUCON International, Inc., 1997).

Cost analyses comparing 12 technologies were preformed by Science Applications International Corporation (SAIC). Six of the technologies used solvent destruction while the remaining technologies used recovery and recycle methods. The cases were run using four different trichloroethylene (TCE) and perchloroethylene (PCE) concentrations. Operation time was assumed to be for about 8000 hr per year. A summary of capital costs is outlined in Table 1, with figures shown for 95% recovery. At 5000 ppm, the destruction technologies require the least capital costs with the exception of regenerative thermal oxidation. The cost for oxidation technologies does not include any cost for scrubbing, which would be required for the off-gas from incineration of chlorinated hydrocarbons. Carbon adsorption with either off-site regeneration or on-site regeneration also show low capital cost. However, the model assumes that steam is available on site. If steam is not available on site, the required boiler would raise the capital cost significantly.

Next in line is the decoupled Brayton system, with costs about 1.5 to 2 times higher than the previous technologies. At 600 and 100 ppm, carbon adsorption with off-site regeneration or the decoupled Brayton regeneration has the lowest cost, largely because the equipment is smaller. The destruction technologies do not show a lower cost because the size of the equipment depends on the volume of incoming air rather than the amount of solvent in the incoming air. With the exception of the Brayton system, the capital costs of the recovery technologies are significantly higher, even at low concentrations.

TABLE 1 Capital and Operating[a] Cost of Control Technologies

	Solvent Concentration (ppmv)							
	5000	1400	600	100	5000	1400	600	100
Technology	Capital Cost, $000				Operating Cost, $000/year			
BRAYSORB	647	477	481	489	202	163	164	166
Carbon adsorption with steam regeneration	136	53	50	50	97	69	67	66
Carbon adsorption with Rankine regeneration	699	627	704	860	215	197	215	252
Decoupled BRAYSORB	225	82	48	16	276	104	61	31
Carbon adsorption with off-site regeneration	152	50	24	6	3270	1079	523	122
BRAYCYCLE	426	432	437	441	115	118	119	124
Direct Rankine condensation	573	679	747	881	146	173	193	235
Thermal oxidation	51	51	51	51	108	108	108	108
Recuperative thermal oxidation	98	98	98	98	98	98	98	98
Regenerative thermal oxidation	580	580	580	580	120	120	120	120
Catalytic oxidation	113	113	113	113	90	110	90	90
Recuperative catalytic oxidation	169	169	169	169	102	102	102	102

Source: D14264D, Enneking and Priebe, 1993.

[a] Cost per year.

TABLE 2 Full-Scale Cost Estimates of Brayton Cycle Solvent Recovery Heat Pump

Flow Rate	VOC Concentration (ppm)	Unit Cost[a]	Unit Cost[b]
100 cfm[c]	50	136	32
	100	71	19
	140	20	8
	500	16	7
	1000	13	7
	2000	10	6
500 cfm	50	32	11
	100	20	8
	140	16	7
	500	9	6
	1000	8	6
	2000	7	6

Source: D14334A, Cummings and Booth, 1996.
[a]Dollars per pound of VOC recovered in first year.
[b]Dollars per pound of VOC recovered after 10 years of operation.
[c]cfm, cubic feet per meter.

In comparing operating costs, destruction technologies were found to be most cost effective at high concentrations. As the concentration decreases, costs decrease for the recovery technologies while cost for the destruction technologies remains constant. At 600 and 1400 ppm the decoupled Brayton system, direct Brayton and on-site steam regeneration offers competitive costs. At 100 ppm, the decoupled Brayton system offers the lowest operating cost. The operating cost comparison of the 12 technologies are included in Table 1. Destruction technologies are most cost effective at high concentrations while the decoupled Brayton cycle is most effective at low concentrations. However, if high initial concentrations are expecting to fall off rapidly to low concentrations, the Brayton cycle would prove cost effective overall (D14264D, p. 5–6).

Full-scale operation costs were compared for the Brayton cycle at varying VOC concentrations. The unit costs for VOC recovery are compared in Table 2. The total capital required is $156,173. This price encompasses the equipment costs, including building, site preparation and freight, and capital costs, which include design, inspection, and management (D14334A, p. 64).

A full-scale demonstration was performed at the Savannah River Site in Aiken, South Carolina. Spread out over 10 wells, the total operating cost of the project was $25,400 per well in addition to $124,000 per well capital costs (D14264D, p. 10).

T0567

N-Viro International Corporation

N-Viro Soil

Abstract

The N-Viro process for alkaline stabilization of municipal sewage sludge combines dewatered sludge with one or more alkaline industrial by-products. The process destroys pathogens by a

TABLE 1 N-Viro Costs at Various Facilities

Facility Location	Operations and Maintenance Cost Plus per Wet Ton
Middlesex, New Jersey	$23.46
Onondaga County, New York	$31.29 (includes distribution and marketing cost)
Ft. Meade, Florida	$17.25
Toledo, Ohio	$18.12
Anderson, Indiana	$27.93
Leamington, Ontario, Canada	$35.38
Athens, Tennessee	$16.20

combination of high pH, heat, and drying. The final product, N-Viro soil, is a soil-like material that is being used as an agricultural lime substitute, soil amendment, and soil substitute.

This technology is currently commercially available.

According to the vendor, the technology has several advantages:

- Produces a commercially valuable product.
- Is cost effective.
- Uses existing facilities and personnel.

Based on a study comparing N-Viro soil physical properties with those of mineral soils, the physical characteristics of N-Viro soils suggest that chemical characteristics (such as high initial pH, acid neutralizing capacity, and high soluble salt content), rather than physical attributes, are likely to limit the use of these materials as soil substitutes.

Technology Cost

According to the vendor, the N-Viro soil process can cost less than other alkaline stablilization technologies because it requires little capital, uses existing space and low cost alkaline by-products, and produces a valuable, consumer-accepted product (D20597K, pp. 4, 5).

The total cost for the N-Viro process is $125 to $150 per dry ton (D15409G). Actual prices will vary at different N-Viro facilities. Table 1 gives several examples.

Information Sources

D15409G, vendor literature

D20597K, N-Viro International Corporation, 1999

T0568

The Oak Hill Company, Ltd.

In Situ Saturated Zone Treatment

Abstract

The In Situ Saturated Zone Treatment (ISSZT) is a commercially available, U.S. Patented technology that separates groundwater from contaminated soil by applying and maintaining low-pressure air to the contaminated area. The groundwater level in the contaminated area is

TABLE 1 Construction and Annual Operating Cost for Sites Using the ISSZT Technology[a]

Area of Site (acre)	Depth of Added Barrier (ft)	Construction Costs	Annual Operating Costs
0.25	25	$250,000	Not given
3	15	$1,000,000	$10,000
8	20	$2,000,000	Not given
7	35	$1,000,000	$50,000
0.75	0	0[b]	$10,000
0.33	40	$400,000	$10,000

Source: D15340C, The Oak Hill Company, Ltd., 1997.
[a] Information is provided by the vendor.
[b] Needed operating facilities were already on-site, no additional capital cost was required.

lowered and maintained at a predetermined depth, creating a vadose zone in which remediation takes place. The technology is ideal for contaminated areas that are next to bodies of water.

For ISSZT, a physical barrier, such as a slurry wall or vertical membrane barrier, is installed around the area of contamination to a depth that will be slightly below the future lowered groundwater level to limit the escape of air from the area. Existing clay or silt may serve as a cap for the system, otherwise a man-made cap is installed. Wells are installed into the soil to inject the low-pressure compressed air beneath the cap. As the air pressure increases, the groundwater is lowered. The injected air is prevented from escaping by the cap at the top, the barrier along the sides, and the water table at the bottom.

The vendor states that tetrachloroethane (PCE), trichloroethene (TCE), and other volatile compounds are difficult to remove from saturated soils because they are relatively insoluble. The vendor states that the technology is especially applicable to sites contaminated with dense non-aqueous-phase liquids (DNAPLs). Using the ISSZT technology creates an unsaturated zone from which these contaminants can be readily air stripped. Other contaminants such as polychlorinated biphenyls (PCBs) or metals can be isolated from groundwater and contained within barriers preventing the spread of contamination.

The vendor states that for some applications, such as the removal of DNAPL from bedrock, the technology can be prohibitively expensive. All information is from the vendor and has not been independently verified.

Technology Cost
The estimated costs for operation and construction of the ISSZT at various sites are presented in Table 1. The vendor states that for some applications, such as the removal of DNAPL from bedrock, the technology can be prohibitively expensive (D17133F, p. 20).

Information Sources

D15340C, The Oak Hill Company, 1997
D17133F, Industrial Wastewater, 1997

T0569

Oak Ridge National Laboratory

Glass Material Oxidation and Dissolution System

Abstract
Oak Ridge National Laboratory (ORNL) is developing the glass material oxidation and dissolution system (GMODS) for the treatment and stabilization of plutonium- or halogen-containing

materials, such as ceramics, metals, organics, and amorphous solids. A glass waste form is the preferred method for stabilization of radioactive wastes. To be successfully vitrified, a material must be in an oxide or oxidelike form prior to vitrification. This requirement presents difficulties when processing plutonium, which is normally purified to a metallic form for industrial or military use. The GMODS system uses lead oxide to oxidize metals and organic materials for the formation of a borosilicate glass. GMODS has been demonstrated on a laboratory scale (100- to 200-g samples) using a variety of feeds, including aluminum, carbon, cerium (a plutonium surrogate), uranium, and stainless steel. Significant development work still remains on GMODS technology. The technology is not currently available commercially.

According to ORNL, the GMODS system has the following advantages:

- Converts plutonium to a glass with minimal processing and handling.
- Minimizes off-gas treatment requirements.
- Allows for single-vessel treatment option.
- Converts secondary wastes to a high-quality glass waste form.

To avoid nuclear criticality, each batch of plutonium must be homogeneously dissolved before new batches are added. Total plutonium in the system should be kept below 5 kg so that criticality (nuclear chain reactions) cannot occur. The melter geometry may also limit plutonium content in the system.

The boron–plutonium ratio in the molten glass must not exceed the boron–plutonium ratio in the desired product glass. The molten glass composition must ensure that all plutonium is dissolved.

Technology Cost

Process economics of the GMODS are dependent on the scale of operation (D14276H, p. 5). Based on theoretical considerations (the limited number of process steps), GMODS has the potential to be a relatively low-cost process for treatment of radioactive wastes (D14276H, p. 37). In some cases, specialized equipment may be used to minimize waste volume prior to treatment, in an effort to minimize costs (D14276H, p. A-3).

Information Source

D14276H, Forsberg and Beahm, 1996

T0570

Oak Ridge National Laboratory

SRTALK Process for Technetium Extraction

Abstract

The U.S. Department of Energy (DOE) is trying to develop an efficient solvent extraction and stripping process to remove the fission products technetium-99 (^{99}Tc), strontium-90 (^{90}Sr), and cesium-137 (^{137}Cs) from alkaline tank wastes, such as those stored at Hanford and Oak Ridge. The SRTALK process uses a crown ether in a modified kerosene to remove technetium (Tc) in the form of pertechnetate from alkaline tank waste; strontium (Sr) can be co-extracted from certain wastes, such as Oak Ridge Melton Valley Storage Tank (MVST) waste. By developing new technologies, significant cost savings would be realized due to the reduced volume of waste committed to geologic repositories and minimized secondary waste streams. Due to the complicated and variable mixtures of salts in the discussed aqueous tank waste, highly efficient and selective separation methods are needed. Although the solvent extraction method may be

viewed as an alternative technology, the developers prefer to suggest that it enhances solid-phase extraction technology.

Advantages of the SRTALK process include the following:

- Direct treatability of the waste
- Safe, economical, and efficient stripping using only water or dilute acidic solution
- No additions of chemicals to the extraction or stripping cycle
- Use of dilutants with high flash point, low toxicity, and low water solubility
- Large volume reduction
- No required feed adjustment
- Low consumption of materials
- Back-end concentration options
- Excellent compatibility with vitrification

Technology Cost

There is no available information regarding the costs associated with this technology.

T0571

Oak Ridge National Laboratory

In Situ Chemical Oxidation through Recirculation (ISCOR)

Abstract

In situ chemical oxidation through recirculation (ISCOR) is a delivery system used to transport oxidants to the subsurface and destroy contaminants in situ. The system uses multiple vertical and horizontal, injection and extraction wells to create a recirculation cell. The cell distributes an oxidant such as hydrogen peroxide or the Carus Chemical Company's CAIROX potassium permanganate (RIMS2000 technology summary number T0144) throughout the treatment area. ISCOR is best suited to treat hot spots or pockets of dense, non-aqueous-phase liquids (DNAPLs) in aquifers. The technology is not currently commercially available.

According to the developer, some advantages of the ISCOR system are that it:

- Offers better control over oxidant migration in the subsurface.
- Injects higher volumes of oxidant solution because soil pore waster is extracted prior to oxidant injection.
- Reduces the costs and effort associated with transporting oxidant solutions to remote sites.
- Destroys contaminants in situ.
- Minimizes site disturbance.

ISCOR technology is most applicable to aquifers with hydraulic conductivities greater than 10^{-4} cm/sec. Vertical and horizontal heterogeneities within the aquifer will affect the oxidant's path and distribution rate through the aquifer. Heavy rainfall can back up water in the injection wells or trip the leak detectors and shut down the ISCOR system. Suspended solids from the precipitation of manganese(IV) oxide, undissolved oxidant, or other sources can cause clogging in the injection and extraction wells and uneven distribution of the oxidant.

Technology Cost

The total cost of the ISCOR field demonstration at the U.S. Department of Energy's (DOE's) Portsmouth Gaseous Diffusion Plant in Piketon, Ohio, was $562,000. These costs do not include

TABLE 1 Total Costs for the ISCOR Demonstration at the U.S. DOE Portsmouth Gaseous Diffusion Plant in Piketown, Ohio

Item	Cost
Project planning and management	$56,000
Pretreatment sampling and mobilization	$163,000
Operations and maintenance	$163,000
Posttreatment sampling	$101,000
Resistivity monitoring	$68,000
Support	$11,000
Total Costs	$562,000

Source: Adapted from D18766A.

well construction. The demonstration was conducted using existing horizontal wells. The ISCOR system was used to treat contaminated soil and groundwater (D18766A, p. 17). Table 1 shows the breakdown of these costs. Unit costs for the ISCOR demonstration were $101/yd^3 of soil treated (D20940F, p. 19).

The DOE used the above site data to produce a cost estimate of ISCOR technology. The estimate was prepared for the treatment of a DOE site with the associated departmental contractor rates, which are generally higher than contractor rates at industrial sites. Estimates involve three trichloroethylene (TCE) mass scenarios (8000, 16,000, and 25,000 lb of TCE to be treated). In each case, it was assumed that ISCOR treatment would only be used to treat the zone of highest contamination (hot spot treatment) (D20940F, pp. 17–18).

For the three DOE scenarios, treatment cost are estimated to be:

- $778/lb for a 8000-lb TCE mass
- $451/lb for a 16,000-lb TCE mass
- $363/lb for a 25,000-lb TCE mass (D20940F, p. 19)

According to DOE research, contaminant depth will be a significant factor in overall project costs. This is due to the costs of installing horizontal or vertical wells. Other contributing factors to ISCOR costs include duration of treatment and the volume/mass of contaminants requiring treatment (D20940F, p. 16).

In June 2001, the Interstate Technology Regulatory Cooperation (ITRC) Work Group published technical and regulatory guidelines for in situ chemical oxidation of contaminated soil and groundwater. The guidance document contains information that can be used in preparing cost estimates for chemical oxidation technologies. For more information, please see D22442A, Appendix D.

Although many of the costs for chemical oxidation technologies will be site specific, chemical costs will generally average 15 to 30% of the total remediation costs. Factors that influence chemical costs will include the chemical oxygen demand (COD) of the contaminated media, pH, the size of the site, and initial contaminant concentrations (D22442A, pp. 19, D-1).

Information Sources

D18766A, U.S. EPA, 1998

D22442A, Interstate Technology and Regulatory Cooperation Work Group, 2001

D20940F, U.S. DOE, 1999

T0572

Oak Ridge National Laboratory

Mercury Removal by Reactive Leaching

Abstract

Mercury removal by reactive leaching is a patented, ex situ process for the remediation of mercury-contaminated soil and solid wastes. It combines the use of a leaching solution with soil washing techniques. A solution containing iodine and potassium iodide is used as the leaching agent. Researchers state that the solution is efficient for extracting most mercury compounds (oxides, sulfides, halogens, and metallic mercury).

In the mercury removal process contaminated media are treated with the leaching solution, which acts as an oxidant-complexing agent. The oxidant oxidizes the mercury to a form that can then be solubilized by the complexing agent. The mercury-containing liquid phase is then separated from the solid media. Depending on treatment objectives, the liquid phases may or may not be further treated to separate the elemental mercury from the oxidant-complexing agent, which can then be reused. It is not known if this technology is commercially available.

Technology Cost

No available information.

T0573

O'Brien & Gere Engineers, Inc.

Mechanical Volatilization Screening

Abstract

Mechanical volatilization screening (MVS) is an ex situ technology that treats excavated soils containing volatile organic compounds (VOCs). The mobile MVS treatment unit consists of a screening plant that aerates soil. The mechanical action of sieving and pulverizing the soil allows the surface area of the contaminated soils to be exposed to the atmosphere, thereby enhancing volatilization of the VOCs from these soils. Soil samples are then analyzed and air monitoring is performed to document that VOC concentrations are below regulatory guidelines.

The MVS technology is commercially available and was used to remediate soil contaminated with VOCs from a leaking underground storage tank at a Superfund site in upstate New York. The MVS technology was selected to remediate this site over bioventing and soil vapor extraction systems.

Dusts and volatile emissions may be generated during the MVS technology, requiring dust control methods to minimize particulate emissions. Also, the handling and processing of soils may require the use of amendments to reduce the moisture content of the soils to be processed.

Technology Cost

The MVS process was used to remediate a site contaminated with VOCs in upstate New York. According to the vendor, estimated processing costs for the MVS technology are approximately \$50/yd^3 of soil (processing costs for a soil vapor extraction system at this site were estimated to be \$150/yd^3). Total project costs (design and construction), including a separate groundwater remediation project at the site, came to less than \$900,000 (D14656P, pp. 581–582).

Information Source

D14656P, Towers, date unknown

T0574

Ocean Arks International and Living Machines, Inc.

Living Machine/Restorer

Abstract
The Living Machine is a treatment technology that uses engineered, simulated ecosystems to treat contaminated surface water, wastewater, and sludge. The system degrades organic contaminants, controls odors, and removes suspended solids from the influent using a combination of living organisms. Although the Living Machine is most commonly used to treat wastewater, the Living Machine/Restorer has been developed to treat contaminated surface water in situ. The technology is commercially available.

According to the vendor, the Living Machine has several advantages:

- Is resistant to "shock loads" in the waste stream.
- Reduces the costs of wastewater treatment.
- Is modular and can be expanded.
- Treats sewage and organic waste.
- Is easy to operate and maintain.

The introduction of high levels of drugs, enzymes, or chemicals may damage the biological components of the system. Cold weather can also reduce system efficiency. A greenhouse and source of artificial heat may be required in colder climates.

Technology Cost
While no cost information is available on remediation applications of the technology, the vendor states that the installed costs for Living Machine system designed to treat wastewater starts around $100,000 (D203645, p. 4).

In San Francisco, California, a pilot facility that treated 50,000 gal of municipal wastewater per day cost $120,000. The 30,000-gal/day Living Machine in Jeffersonville, Vermont, cost $300,000 to build. The engineering, installation, and training associated with the Living Machine at the Darrow School in New Lebanon, New York, cost approximately $250,000 (D18016F, p. 1; D18227O, p. 2; D20921C, p. 1; D20918H, p. 2).

A full-scale Living Machine treats 32,000 gal of wastewater per day at a chocolate factory in Henderson, Nevada. The maintenance costs associated with the system are approximately $8000 per year for bacteria and $30 per day for power to run the pumps. In colder climates, electrical charges may increase during the winter months (D20916F; D21941K).

Based on the demonstration funded by the U.S. Environmental Protection Agency in Frederick, Maryland, the vendor estimated the costs associated with building and maintaining a Living Machine for the treatment of municipal wastewater. Table 1 displays the capital costs for Living Machine systems that process 40,000 gal per day (gpd), 80,000 gpd, and 1,000,000 gpd. The operations and maintenance costs for the systems are shown in Table 2. Table 3 demonstrates the total annual costs for the systems (D22581K, pp. 13-9–13-13).

Information Sources

D18016F, vendor information
D18227O, Edgar, 1997
D203645, Living Technologies, undated
D20916F, Chin, 1997
D20918H, Riggle and Gray, 1999

TABLE 1 Estimated Capital Costs for Living Machine Municipal Wastewater Treatment Plants

System Flow Rate (gpd)	Capital Costs with a Greenhouse	Capital Costs without a Greenhouse
40,000	\$428,875	\$374,814
80,000	\$613,257	\$538,089
1,000,000	\$4,703,026	\$4,214,987

Source: From D22581K.

TABLE 2 Estimated Annual Operation and Maintenance Costs for a Living Machine Municipal Wastewater Treatment Plant

	40,000 gpd		80,000 gpd		1,000,000 gpd	
Parameter	With Greenhouse	Without Greenhouse	With Greenhouse	Without Greenhouse	With Greenhouse	Without Greenhouse
Energy	\$9,000	\$9,000	\$13,666	\$13,666	\$125,443	\$125,443
Bioaugmentation	\$4,300	\$4,300	\$5,450	\$5,450	\$31,500	\$31,500
Methanol additions	\$2,901	\$2,901	\$5,802	\$5,802	\$10,800	\$10,800
Contingencies	\$1,080	\$1,080	\$1,688	\$1,688	\$15,604	\$15,604
Gasoline	\$3,231	\$0	\$4,438	\$0	\$70,088	\$0
Labor	\$26,000	\$26,000	\$78,000	\$78,000	\$327,600	\$327,600
Sludge disposal	\$2,000	\$2,000	\$4,000	\$4,000	\$50,000	\$50,000
Maintenance	\$4,288	\$3,748	\$6,132	\$5,380	\$47,030	\$42,150
Horticulture revenue (income)	−\$2,400	−\$2,400	−\$3,300	−\$3,300	−\$35,000	−\$35,000
Total	\$50,400	\$46,629	\$115,876	\$110,686	\$643,065	\$568,097

Source: From D22581K.

TABLE 3 Estimated Total Annual Costs for a Living Machine Municipal Wastewater Treatment Plant

System Configuration	Capital Costs	Operation and Maintenance Costs	Present Worth	Total Annual Costs
40,000 gpd with greenhouse	\$428,875	\$50,400	\$960,500	\$90,900
40,000 gpd without greenhouse	\$374,814	\$46,629	\$866,700	\$82,000
80,000 gpd with greenhouse	\$613,257	\$115,876	\$1,835,600	\$173,800
80,000 gpd without greenhouse	\$538,089	\$110,686	\$1,705,700	\$161,500
1,000,000 gpd with greenhouse	\$4,703,026	\$643,065	\$11,486,700	\$1,087,000
1,000,000 gpd without greenhouse	\$4,214,987	\$568,097	\$10,207,800	\$966,000

Source: From D22581K.

D20921C, Gourlay, 1999
D21941K, Forster, 1997
D22581K, U.S. EPA, 1996

T0575

Oceaneering International, Inc.

ROVCO₂

Abstract
Oceaneering International, Inc., is developing the remote operated vehicle with carbon dioxide (CO_2) blasting ($ROVCO_2$) system for the U.S. Department of Energy (DOE). In $ROVCO_2$ technology, a robotic vehicle uses the Cryogenesis® subsurface decontamination system to blast pellets of CO_2 at the contaminated surface. The dry ice pellets impact the contamination and undergo sublimation (direct phase change from solid to gas). This serves to break the bond between the contaminants and the surface, lifting them off where they can be removed by the pressurized spray. The CO_2 and contaminants pass through an attached vacuum filter system, leaving only the removed material for disposal. The $ROVCO_2$ system is not commercially available, but the Cryogenesis decontamination system used in the robot is commercially available.

The vendor claims the following advantages of $ROVCO_2$ technology:

- Lowers operator exposure to hazardous conditions and supports functional automation of repetitive tasks.
- Effectively removes coatings and contaminants from concrete floors.
- Removes contaminants without the generation of additional waste products.

Performance of the unit has proven to be dependent on the level of decontamination required and on the type of coating covering the decontamination. An evaluation of the technology noted that the reliability of the equipment was low and that the system had a low production rate. Wastes recovered by this process may require additional treatment or disposal as radioactive, mixed, or hazardous wastes.

Technology Cost
According to information supplied by the vendor in 1996 (during phase 2 testing), the estimated operational cost was $0.72/ft^2. This amount included waste disposal (D15497W, p. 2).

In 1998, V. Renard of Oceaneering International published an economic evaluation comparing the $ROVCO_2$ system with shot blasting and soda blasting technologies. Capital costs of the systems varied significantly. The cost of a $ROVCO_2$ system was estimated at $457,000. Total unit costs for removal and disposal using the $ROVCO_2$ system were estimated to be $0.84/ft^2 decontaminated. The comparison is summarized in Table 1 (D17471U, p. 3).

In 1999, the Hemispheric Center for Environmental Technology published an evaluation of technologies that could be used to decontaminate metals and masonry. They reported that the $ROVCO_2$ system used during the evaluation cost $304,000. The unit required supporting equipment, including an air compressor ($75,700), an air cooler ($9700), a desiccant air dryer ($27,700), and a carbon dioxide pelletizer ($39,500). The total cost for supporting equipment was $152,600 (D23005X, p. B-6).

Information Sources

D15497W, Resnick et al., 1996
D17471U, Renard, 1998
D23005X, Hemispheric Center for Environmental Technology, 1999

TABLE 1 Economic Comparison of $ROVCO_2$ with Similar Technologies

Technology	$ROVCO_2$	7-inch Shot Blasting	Soda Blasting
Production rate[a]	10–120 ft^2/hr	NA[b]	120–240 ft^2/hr
Depth of penetration[c]	0.014 inches	0.03125 inches	<0.03125 inches
Solid waste generation[d]	0.0012 ft^3/ft^2	0.0026 ft^3/ft^2	0.007 ft^3/ft^2
Liquid waste generation[e]	None	None	1.9 gal/ft^2
Disposal unit costs[f]	\$0.16/ft^2	\$0.35/ft^2	\$1.14/ft^2
Removal unit costs[g]	\$0.68/ft^2	\$2.18/ft^2	\$5.62/ft^2
Total costs for removal and disposal	\$0.84/ft^2	\$2.53/ft^2	\$6.76/ft^2
Estimated capital costs	\$475,000	\$4,000,000	\$30,000–35,000

Source: Adapted from D17471U.
[a] Production rate depends on level of contamination and coating type.
[b] NA, not applicable.
[c] Based on removing epoxy 3 mil thick, and >1 mil concrete removal.
[d] Cubic feet of waste per square foot of area decontaminated. This amount includes the generation of the above amount of removed concrete plus a 20% volume expansion factor.
[e] Gallons per square foot of area decontaminated.
[f] Disposal costs are estimated to be \$1000 per drum, which is equivalent to \$136/ft^3.
[g] Removal costs for the $ROVCO_2$ system are based on a productivity rate of 100 ft^2/hr (a rate achievable for removing light nonepoxy paints) and labor rate including a one-person team at \$37/person/hour. Removal costs for soda blasting are based on a productivity rate of 120 ft^2/hr (a rate achievable for removing light nonepoxy paints) and labor rate including a two-person team at \$37/person/hour.

T0576

Oil Waste Treatment Company

Terrazyme Phase Segregation

Abstract

The Terrazyme phase segregation technology was developed to be a volume reduction system for use on wastes with high water contents. It is a chemically enhanced, mechanical separation process for segregating waste into a liquid and a solid phase.

The Terrazyme technology is intended for use on wastes such as bio sludges, industrial sludges, grease trap wastes, grit trap wastes, and other wastes with high liquid contents that must otherwise be solidified prior to landfilling.

This technology was developed by the Oil Waste Treatment Company and its parent company, North American Technologies Group, as an alternative to solidification. Terrazyme is no longer commercially available from this vendor. The company was closed for business as of early 1999.

Technology Cost

There is no available information regarding the costs associated with this technology.

T0577

On-Site Technologies (OST)

Modular Interchangeable Treatment System (MITS)

Abstract

The modular interchangeable treatment system (MITS) contains soil vapor or groundwater treatment units that are integrated into remediation systems designed specifically for a particular site.

The technology effectively treats large contaminated areas or sites where multiple technologies are required over the life cycle of the remediation project. The MITS line consists of remediation technologies including filtration, ultraviolet destruction, incineration, bio-treatment, product recovery, air strippers, sparging, soil venting, ozone and peroxide oxidation, and adsorption. The technology remediates soil and groundwater contaminated with gasoline; benzene, toluene, ethylbenzene, and xylene (BTEX); methyl tertbutyl ether (MTBE); aliphatic hydrocarbons; diesel; petroleum-based solvents and thinners; and oil and grease. Many of the systems remove halogenated volatile and semivolatile organic compounds and light non-aqueous-phase liquids.

The patent pending MITS technology is commercially available through the vendor. All information is provided by the vendor and has not been independently verified.

Technology Cost

The vendor claims that MITS are significantly more cost-effective than technologies produced

TABLE 1 Cost Estimate for Modular Integrated Treatment System (MITS) Technology (thousand of dollars)

Parameters	1	2	3	4	5	6	7	8	Total
Design	0	0	0	0	0	0	0	0	0
Const	0	0	0	0	0	0	0	0	0
Site prep	75	50	25	50	0	0	0	0	200
Demo	0	0	0	0	0	0	0	0	0
Transfer	0	0	10	5	0	10	0	0	25
Equip	0	0	0	0	0	0	0	0	0
MITS	240	95	0	75	0	0	0	0	410
Total	315	145	35	130	0	10	0	0	635

Source: Adapted from D15390M, On-Site Technologies.

TABLE 2 Cost per Cubic Yard of Soil Treated with MITS Technology

Client	Volume Treated (yd^3)	Cost per Cubic Yard ($)
Coast Oil Bulk Plant	32,000	37.50
Sorrento Cheese Company, San Jose, California	3,700	67.50
Rotten Robbie Service Station, Rohnert Park, California	72,600	11.00
Schweickhardt Estate, Santa Clara, California	12,100	25.00
Pacific Nursery Pots, Santa Clara, California	12,100	31.00

Source: Adapted from D15481O, VISITT 4.0, 1995.

using conventional design/construction approaches (D15389T, p. 5). On-Site Technologies (OST) estimated the costs of the MITS technology for the remediation of an oil company's eight sites with soil and groundwater contamination. A mixture of MITS treatment modules were used based on site cleanup needs. Over an 8-year period the vendor estimated that the total equipment/construction costs for the MITS technology would total $635,000. The breakdown of these costs are given in Table 1. In addition, the cash flow for MITS was estimated at $2,011,000 while the profit and loss costs for MITS was $635,000 (D15390M, p. 5).

The MITS technology has been used at various sites. The remediation costs for each site is presented in Table 2.

T0578

OnSite Technology, L.L.C.

Portable Indirect Thermal Desorption (ITD)

Abstract

OnSite Technology, L.L.C. (OnSite) has developed the portable indirect thermal desorption (ITD) system for the treatment of hazardous wastes. The ITD 6000 uses a rotating, heat-jacketed closed barrel to vaporize hydrocarbons from contaminated soils and drilling mud, allowing the hydrocarbons to be recovered while cleaning the contaminated sediment. The technology is commercially available.

This technology is applicable to sites with hydrocarbon-contaminated soils, including drill cuttings, oil-contaminated soil around tank batteries and refineries, oil field service and storage facilities, and service stations.

The vendor claims that ITD technology removes more than 99.9% of the hydrocarbons from contaminated soils, allowing customers to use more efficient, oil-based drilling muds and recycle the reclaimed hydrocarbons from the drill cuttings.

Information presented in this summary consists of vendor claims and have not been independently verified.

Technology Cost

There is no available information regarding the costs associated with this technology.

T0579

On-Site Thermal Services Division of Soil Restoration and Recycling, L.L.C.

Low-Temperature Thermal Desorption Plant

Abstract

On-Site Thermal Services Division of Soil Restoration and Recycling, L.L.C.'s (SR2's) Low-temperature thermal desorption (LTTD) plant is an ex situ technology for treating soil contaminated with petroleum and chlorinated hydrocarbons.

Contaminated soil is fed into a rotary dryer where the temperature is raised to between 500 and 800°F. As the soil is heated, moisture and volatile organic compounds (VOCs) are vaporized. The heated exhaust gases from the dryer are forced through a baghouse where soil fines and dust particles are removed. Exhaust gases are then passed through a catalytic oxidizer to remove hydrocarbons.

SR2 owns four portable LTTD plants including two 4-ft (rotary drum internal diameter) units, one 5-ft unit, and a 6-ft unit.

The 4-ft unit is primarily used to treat soils contaminated with gasoline, diesel, jet fuel, oil, mineral oil, and kerosene. The 5-ft and 6-ft parallel flow LTTD units are designed to treat Bunker C oil, crude oil, and creosote soil contaminants. These plants can also treat soils contaminated with chlorinated hydrocarbons, pesticides, and solvents.

The 5-ft and 6-ft parallel flow LTTD units are manufactured by Astec Industries, Inc.

This technology is currently commercially available. SR2 has permits to operate LTTD plants in 11 states: Arizona, Arkansas, California, Georgia, Idaho, Nevada, New Mexico, Oregon, Texas, Utah, and Washington. Permits to treat chlorinated hydrocarbons have been issued by Arizona and the South Coast Air Quality Management District (SCAQMD) in California.

There are several limitations to LTTD plant technology. Soil moisture content greater than 15% by weight and very high percentage of fines can adversely affect unit operations.

Organic-bound lead and sulfur compounds can reduce catalytic oxidizer performance and increase treatment costs due to added maintenance requirements. The pulse-jet baghouse is unable to remove submicron particulates from exhaust gases. The LTTD is unable to treat contaminants with boiling points greater than 900°F.

Technology Cost

The cost for this technology is $40 to $250 (1995 dollars) per ton of waste treated. These estimates do not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals.

Factors that have a significant effect on unit price include the following:

- Target contaminant cleanup concentration
- Initial contaminant concentration
- Quantity of waste
- Moisture content of soil
- Amount of debris with waste
- Site preparation
- Waste handling/preprocessing
- Characteristics of soil
- Utility/fuel rates (D10325T, p. 34)

Information Source

D10325T, VISITT Version 4.0, 1995

T0580

Onsite* Ofsite, Inc.

Petroleum Sludge Treatment

Abstract

The petroleum sludge treatment (PST) is a separation technology for the treatment of petroleum sludges from the oil refining industry. This technology is able to separate emulsified sludges into three distinct phases: oil, water, and solids. PST significantly reduces the amount of waste requiring disposal and recovers valuable oil that can be returned back to the refinery.

The anticipated application of this technology is for the treatment of emulsified petroleum sludges that result from crude oil refining operations. These sludges include American Petroleum Institute (API) separator sludge, sludge from dissolved air flotation (DAF) units, slop oil emulsion sludges, and heat exchanger cleaning sludges. Other proposed applications may include the

use of PST units on ships, which could recover and treat oil from oil spills, without the effort and delay of transporting the oil emulsion to shore for treatment.

Onsite* Ofsite, Inc. closed for business in late 1999, and this technology is not commercially available.

Technology Cost
The developers estimate the operating costs for a full-scale version of the PST process will typically be less than the value of the recovered oil. Estimates are that the operating costs will be about $25 per ton. Installed capital costs are estimated to be about $2 million, or $10 to $15 per wet ton feed sludge capacity (D15507H, p. 1; D13883U, p. 41). However, the actual costs of the technology may vary from this because at this point in time these estimates are based only on laboratory-scale experiments.

Information Sources

D13883U, Hazmat World, 1991
D15507H, Pacific Northwest National Laboratory, 1996

T0581

Onsite* Ofsite, Inc.

Thermochemical Environmental Energy System

Abstract
The Thermochemical Environmental Energy System™ (TEES™) is a technology for catalytically converting organics in water to methane, carbon dioxide, and clean water. In the process waste is eliminated and an energy product is created.

This technology has potential applications that range from treating hazardous organics in industrial process streams and contaminated water to treating wet, solid, organic wastes such as dairy and agricultural residues. Other possible applications include waste treatment for the chemical manufacturing, petroleum refining, and forest products industries.

TEES is capable of treating several classes of organic compounds, including aliphatics, aromatics, chlorinated aliphatics and aromatics, polycyclic aromatics, cyanides, amines, phenolics, organic acids, and ketones.

Onsite* Ofsite, Inc. closed for business in late 1999, and the TEES technology is not commercially available.

Technology Cost
There is no available information about the costs associated with this technology.

T0582

Onyx Industrial Services

SOIL*EX

Abstract
The SOIL*EX™ technology is a variation of soil washing for separating and removing radionuclides and hazardous metals while destroying volatile organic compounds. The SOIL*EX technology was demonstrated in 1993 at a pilot plant constructed at the Clemson Technical Center. The technology has not progressed beyond that point and is not being used commercially. According to information from the vendor received in September 1999, the company is closed for business and SOIL*EX is no longer available. SOIL*EX is a patented technology.

Two subsystems of the SOIL*EX technology are ACT*DE*CON™ and PO*WW*ER™ technologies. ACT*DE*CON treatability studies have been performed for commercial clients and plans for full-scale applications exist, but there have been no commercial applications to date.

The SOIL*EX technology has three major components: extraction to chemically separate the contaminants from the matrix using proprietary dilute aqueous-based chelants and other additives (including the ACT*DE*CON reagents and surfactant); dewatering for solid/liquid separation of the treated material; and PO*WW*ER technology utilizing evaporation for concentration of radionuclides, inorganic salts, and heavy metals and catalytic destruction for removal of volatile organic compounds.

No information on the technology's limitations was available.

Technology Cost
No available information.

T0583

Oregon State University

Chitosan Beads

Abstract
Researchers at Oregon State University are currently studying applications of chitosan beads for the removal of toxic metal ions from wastewater. Chitosan has potential applications to waste removal because it selectively adsorbs toxic Group III transition metal ions in preference to less dangerous alkali or alkaline earth metal ions. The technology has been the focus of bench-scale studies and is not commercially available; but it is available for licensing.

Researchers claim that the engineered chitosan beads appear to adsorb selected heavy metals as efficiently as the best commercial processes now being used. They also believe that future research will enable recycling of the metals and reuse of the chitosan. The process also provides an economic use of tons of crab shells (the source of chitosan) that are currently disposed of as trash by the shellfish producing industry.

The process does not stabilize the removed heavy metals, additional treatment is required for recycling or disposal of the removed ions. The crosslinking process renders the chitosan beads insoluble in dilute acid but reduces compression strength and adsorption capacity relative to the uncrosslinked chitosan adsorbent bead. Adsorption capacity of chitosan is reduced as pH decreases.

Technology Cost
Unprocessed chitosan costs approximately $7/lb (D150458, p. 1).

Information Source

D150458, Rorrer, date unknown

T0584

Osprey Biotechnics

Munox

Abstract
Munox® is a line of bacterial products for the biodegradation of organic compounds in wastewater, surface water, groundwater, and soil. Munox, invented by Peter A. Vandenbergh, is the subject of several patents. It is manufactured by and commercially available from Osprey Biotechnics. Munox products have been available since 1982.

Munox products are freeze-dried bacteria that are regenerated on site. They are selected for their ability to degrade certain target contaminants. These bacteria are then introduced into whatever treatment scenario is being used at the site.

All information was supplied by the vendor and has not been independently verified.

Technology Cost

The Munox Standard Multiplier is a 5-gal plastic bottle bag at $29.50 per unit, and the Magnum Multiplier is a 55-gal plastic bottle bag at $290.00 per unit. The Munox XL-2 is a 2.5-gal plastic jug for $28.90, and the XL 249 is a 55-gal plastic bottle bag for $399.00.

Information Sources

D16628T, vendor literature

T0585

Oxidation Systems, Inc.

HYDROX Oxidation Process

Abstract

The HYDROX™ Oxidation Process (HOP) is an advanced oxidation process for treating groundwater and wastewater contaminated with volatile organic compounds (VOCs); benzene, toluene, ethylbenzene, and xylenes (BTEX); and other dissolved organics. HOP uses hydraulic cavitation to create highly reactive hydroxyl radicals in aqueous solutions. These hydroxyl radicals oxidatively degrade organic contaminants in the process influent. When these oxidation reactions are allowed to go to completion, organic contaminants are degraded to carbon dioxide and water. If chlorinated compounds are oxidized, chloride ions are also produced.

This technology was developed by Oxidation Systems, Inc., of Arcadia, California. According to the vendor, the technology is commercially available, and over 30 HOP systems have been built and installed.

Listed advantages of HOP technology include:

- Hydroxyl radicals are generated on site from the water itself, without the need for additional chemicals.
- Organic contaminants are destroyed.
- Process operates more quickly than other techniques (in months, rather than years).

Potential HOP limitations include:

- Some chemical oxidation reactions are pH dependent.
- Process is less cost effective at sites with high contaminant concentrations.
- Compounds in the contaminated media can interfere with contaminant oxidation.

Technology Cost

The vendor estimates that the average cost to operate a HOP system is about 30 cents per 1000 gal of water treated, including chemical and power costs (D15505F, p. 2). However, costs will vary considerably with each application. Capital costs are based on the system's pumping capacity, the cost of the cavitation unit, control instrumentation, and the associated piping (D15503D, p. 4).

Table 1 shows a set of costs derived from an application of HOP technology for the treatment of extracted groundwater at a site in Ontario, Canada. The costs are based on a treatment rate of 30 gal/min, for 355 days of operation per year. Other assumptions include electrical costs of

TABLE 1 Estimated Costs to Operate the HYDROX Oxidation Process

	Cost per 1000 gal ($)	Cost per Day ($)	Cost per Month ($)	Cost per Year ($)
Electricity	0.22	9.58	284	3,400
Hydrogen peroxide (20 ppm)	0.08	3.24	96	1,151
Maintenance	0.25	10.68	320	3,845
Total	0.55	23.50	698	8,396

Source: Adapted from D15504E, p. 2.

5 cents/kWh (for a 7.5-hp pump and 48 ultraviolet lamps), and hydrogen peroxide costs of 63 cents/lb (D15504E, p. 2).

Information Sources

D15503D, Skov and Beale, 1997

D15504E, Oxidation Systems, Inc., date unknown

D15505F, Oxidation Systems, Inc., date unknown

T0586

Pacific Northwest National Laboratory

In Situ Redox Manipulation

Abstract
In situ redox manipulation (ISRM) is an in situ, groundwater remediation technology for manipulating the oxidation–reduction (redox) potential of an unconfined aquifer to immobilize inorganic contaminants (metals, inorganic ions, and radionuclides) and to destroy organic contaminants (primarily chlorinated hydrocarbons).

This is achieved by creating a permeable treatment barrier in the subsurface by injecting reagents, microbes, and/or microbial nutrients. The injected material is selected based on its ability to create reducing agents in the aquifer. A long, linear barrier can be created by overlapping several smaller reduced zones. The barrier acts like a filter to remove contaminants from the groundwater flowing through it.

With the redox potential of the aquifer reduced, ISRM could potentially treat a variety of metals, radionuclides, and chlorinated organic solvents.

This technology has been researched by the U.S. Department of Energy's (DOE's) Pacific Northwest National Laboratory (PNNL) since 1991. Testing resulted in a pilot-scale dithionite injection experiment in 1995. A larger scale treatability study was initiated in 1997. Research on ISRM is ongoing, and the technology is not yet commercially available.

Technology Cost
Table 1 is a comparison of the costs associated with ISRM and pump-and-treat technology. These costs are based on a 1997 study by researchers at the U.S. DOE's Los Alamos National Laboratory. The researchers predicted a 62% cost savings over a 10-year period when using ISRM instead of pump-and-treat to treat chromium-contaminated groundwater (D17151H).

There may be an added cost associated with the disposal of reagent-contaminated water if it cannot be disposed to a publicly owned treatment works (D13486L, p. 158).

The total proposed costs for a full-scale, 2000-ft ISRM barrier at the 100-D area of the DOE's Hanford Reservation in Richland, Washington, are $5 million. The DOE estimated that the design, construction, materials, and reactive material for the installation would cost approximately $480,000 (D206304, p. 1).

TABLE 1 Comparison of Estimated Costs of In Situ Redox Manipulation (ISRM) versus Pump-and-Treat Technology

	Year 1		Years 2 through 10		Totals	
Task	Pump and Treat	ISRM	Pump and Treat	ISRM	Pump and Treat	ISRM
Characterization/ design	$400,000	$560,000	—	—	$400,000	$560,000
Procurement (i.e., reagent, IX resin)	$300,000	$300,000	—	—	$300,000	$300,000
Construction/ barrier emplacement	$1,000,000	$1,100,000	—	—	$1,000,000	$1,100,000
Operating costs	—	—	$650,000	—	$5,850,000	$0
Waste management	—	—	$60,000	$20,000 (year two only)	$540,000	$20,000
Performance monitoring	—	—	$50,000	$260,000	$450,000	$660,000
Project management	$50,000	$50,000	$50,000	$50,000	$300,000	$300,000
Well abandonment	—	—	$5,000 (year ten only	$12,000 (year two only)	$5,000	$12,000
Total					$8,850,000	$2,950,000

Source: Adapted from D17151H, Cummings, 1997.

Information Sources

D13486L, U.S. DOE, 1995

D17151H, Cummings and Booth, 1997

D206304, Remediation Technologies Development Forum, undated

T0587

Pacific Northwest National Laboratory

Permeable Clinoptilolite Barriers for Strontium

Abstract

Studies are being conducted by the Pacific Northwest National Laboratory (PNNL) to investigate the use of clinoptilolite as an in situ permeable barrier to strontium (Sr^{90}) migration in groundwater at the site referred to as the 100-N area of the Hanford Site. This technology uses clinoptilolite to absorb radioactive Sr^{90} from groundwater.

Bench-scale development of this technology has been completed, and design of a field-scale demonstration was scheduled to commence in the summer of 1996.

This technology is not yet commercially available.

Technology Cost

In a 1996 study by the U.S. Department of Energy (U.S. DOE), researchers claimed that one reason that clinoptilolite was chosen over other materials in PNNL's studies is that it is a naturally occurring zeolite and is available at a relatively low cost (approximately $200 per ton). Because this type of system is passive, operational costs are minimal, and external energy is not required to operate the systems once they are installed (D132230, p. 140).

Information Source

D132230, U.S. DOE, 1996

T0588

Pacific Northwest National Laboratory

Self-Assembled Monolayers on Mesoporous Supports (SAMMS)Technology

Abstract

Pacific Northwest National Laboratory (PNNL) is researching the use of self-assembled monolayers on mesoporous supports (SAMMS) technology for the removal of metals and radionuclides from liquid and gaseous hazardous wastes. SAMMS combines two technologies—mesoporous ceramic material and functionalized monolayers. The ceramic material has pores that increase its surface area. This ceramic material is coated with functionalized monolayers that form stable, covalent bonds with the contaminants.

SAMMS has been evaluated in bench-scale and pilot-scale studies. In 1997, Battelle Memorial Institute (Battelle) applied for a patent on SAMMS with the U.S. Patent Office. SAMMS is not commercially available.

Researchers claim that the technology has the following advantages:

- Has a large surface area that allows for high metals loading capacity.
- Is more selective for metals such as mercury, silver, lead, cadmium, nickel, and cobalt than for alkaline and alkaline earth metals.
- Produces a stable waste form that can pass Toxicity Characteristic Leaching Procedure (TCLP) criteria for land disposal.
- Binds different forms of mercury, including metallic, inorganic, organic, charged, and neutral compounds.
- Removes targeted metals from aqueous or organic waste streams.
- Has a small pore size that prevents bacteria from entering the SAMMS to convert the insoluble mercury to more toxic and mobile methylmercury.
- Can be engineered in a variety of forms such as pellets, columns, or films.
- Possesses good mechanical strength and is durable and stable in air or in aqueous solutions (D16682Z, p. 5.17; D18618Z, p. 2).

The information included in this summary is based on bench-scale, proof-of-concept testing.

Technology Cost

In 1997, the U.S. DOE prepared a cost estimate based on bench-scale tests of the SAMMS technology. The theoretical SAMMS would be used to remove low levels of organics and mercury at the Oak Ridge National Laboratory Nonradiological Wastewater Treatment Plant

TABLE 1 Estimated Costs for Different SAMMS Configurations

SAMMS Configuration	Capital Cost (Million $)	Operating and Maintenance (Million $ per year)
Separate column system	1.25–5.0	0.1–0.2
Combining SAMMS with activated carbon	0	0.003–0.03
Skid-mounted columns	0.12	0.1–0.2
Skid-mounted 3M cartridges	0.104	0.1–0.2

Source: Adapted from D17139L.

TABLE 2 Material–Lifetime Cost Comparison for Mercury Removal Technologies

	Technologies		
Cost Factor	SAMMS	GT-73	Activated Carbon
Material cost ($/kg)	150	42	1.78
Mercury loading (g/kg at 0.2 parts per billion)	80	6.5	0.025
Amount of material required for the removal of 1 kg of mercury (kg)	13	154	40,000
Waste disposal cost per kg of mercury removed[a] ($)	60	489	190,000
Total cost per kg of mercury removed ($)	2,010	6,960	261,000

Source: Adapted from D230331.
[a] Based on a disposal cost of $60/ft^3$.

(NWTP). The cost estimates provided in Table 1 reflect the use of SAMMS to meet an effluent limit of 12 parts per trillion for mercury (D17139L, p. 5.5).

Researchers prepared another cost estimate in 1998. The unit cost of the SAMMS technology was $710/kg of mercury removed. The unit costs for competing processes might reach $260,000/kg of recovered mercury (D18428V, p. 2).

The DOE's PNNL compared the costs for mercury removal using SAMMS, GT-73 (an ion exchange resin), and activated carbon. The comparison was based on laboratory equilibrium data for the SAMMS material, manufacturer's performance data for the GT-73, and performance data from full-scale applications of activated carbon (D230331, p. 11). Table 2 presents the cost data provided by PNNL.

Information Sources

D17139L, U.S. DOE, 1997

D18428V, R & D Online, 1998

D230331, U.S. DOE, undated

T0589

Pacific Northwest National Laboratory

Environmentally Benign Digestion Process (EBDP)

Abstract
The environmentally benign digestion process (EBDP) uses nitro-reductase enzymes commonly found in spinach, buttermilk, fungi, bacteria, or porcine heart to reduce explosive compounds

[e.g., trinitrotoluene (TNT), hexahydro-1,3,5-triitro-1,3,5-triazine (RDX), and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)] to low-toxicity nitroaromatic by-products. These by-products can be either used in industry or further reduced to products such as carbon dioxide, ammonia, and water.

Manish M. Shah, Ph.D, the principal investigator, claims the following advantages:

- Rate of degradation 1000 times faster than a microbial system.
- Enzymes are biodegradable, nontoxic, and can be recycled.
- Works at room temperature and pressure.
- Requires minimal capital expenditure.
- Is mobile.

This is an emerging technology being researched at the U.S. Department of Energy's Pacific Northwest National Laboratory. To date, EBDP has only been tested in the laboratory, but field tests are expected in the future. Although the process is ex situ, the equipment can be transported for on-site processing.

Technology Cost
While the process has not yet been field tested, it is expected to have low capital costs since it does not require any special equipment, hardware, or software (D17699C). Another source estimates the price for setting up a processing capability to destroy 1000 kg of explosives per day to be $10,000. The enzymes used cost about $100/kg and are not consumed by the process (D17700O).

Information Sources

D17699C, "Spinach Enzymes Neutralize Explosives," 1998
D17700O, Information Sheet

T0590

PaR Systems, Inc.

Dry Size Reduction System (DSRS)

Abstract
PaR Systems, Inc. (PaR), has developed the dry size reduction system (DSRS) to aid in the decommissioning of former U.S. Department of Energy (DOE) sites and commercial nuclear facilities. After components are removed in situ, they are processed by the DSRS for compact disposal of contaminated materials, while components that have been cleaned below regulatory limits can disposed of without restrictions. The system is designed to decontaminate and size reduce components as large as steam generators. The technology is commercially available, but there is no information on field demonstrations of the system.

All information is from the vendor and has not been independently verified.

Technology Cost
The vendor stated in 1995 that disposal costs for low-level radioactive waste were estimated to be $440/ft^3. Based on their experience from manual operations, the vendor estimated that size reductions of 75 to 90% were possible using the DSRS. The vendor stated that using those factors, and ignoring savings that could be realized in improved safety and efficiency, as well as the limited generation of secondary wastes, the DSRS could pay for itself after processing 10,000 ft^3 of waste (D17270N, p. 1).

Information Source

D17270N, PaR Systems, 1996, vendor literature

T0591

Paragon Environmental Systems, Inc.

Paragon SVE/Oxidizers

Abstract
Paragon has designed a system that combines soil vapor extraction (SVE) and oxidation techniques to remediate petroleum-contaminated soils. The technology uses an SVE unit to volatilize petroleum hydrocarbons. The off-gases from this unit can then be treated using either a thermal or a catalytic oxidation method. The technology is no longer commercially available.

All information in this summary was provided by the vendor and has not been independently verified.

Technology Cost
No available information.

T0592

Passive Soil Vapor Extraction

Abstract
Passive soil vapor extraction (PSVE) removes and recovers underground contaminants by enhancing the natural "breathing" that occurs in soil as a response to changes in atmospheric pressure. This process is sometimes referred to as "barometric pumping." The process is a low-cost complement to conventional active-extraction methods; investment and maintenance are low and no power is needed. The passive process is better suited than conventional methods for certain problems in cleaning up volatile organic compounds from soil, such as at the margins of plumes and for removing residual contaminants after active-extraction methods become inefficient.

Researchers believe that the PSVE technology can be used to remove volatile organic compounds (VOCs), halogenated volatile organic compounds (HVOCs), and total petroleum hydrocarbons (TPH). Some chemicals treated with PSVE include carbon tetrachloride, vinyl chloride (VC), chlorobenzene, 1,1-dichloroethane, dichloroethene (DCE), trichloroethane (TCA), and benzene, toluene, ethylbenzene, and xylene (BTEX).

The primary application of the PSVE technology will likely be to complement active soil vapor extraction efforts. PSVE could also be used on the edge of unsaturated zone contaminant plumes where concentrations of volatile contaminants are low or for enhancement of bioremediation activities. The primary advantages of PSVE application are low capital costs and minimal operating costs. One-way valves may also be incorporated so that the system only takes in or lets out air through wells.

In 1993, a Passive Soil Vapor Extraction Working Group was formed, representing collaborations among Bechtel Corporation, IT Hanford, U.S. Environmental Protection Agency Region 10, Idaho National Engineering Laboratory, Lawrence Livermore National Laboratory, Pacific Northwest National Laboratory, Westinghouse Savannah River Company (WSRC), and Science and Engineering Associates, Inc. A cooperative research and development agreement has been established between WSRC and JND Sterling, Inc., to enhance PSVE with solar-powered pumping. This technology is still in development and is not yet commercially available.

TABLE 1 Comparative Costs of Active versus Passive Vapor Extraction for Removal of Carbon Tetrachloride (CCl_4)

Contaminant Concentration	Active Vapor Extraction at 500 cfm	Passive Vapor Extraction: 50 Wells at 10 cfm	100 Wells at 5 cfm	500 Wells at 1 cfm
5 (ppm)	1046($/lb)	411($/lb)	813($/lb)	4040($/lb)
50	110	49	89	412
100	58	29	49	211
200	32	19	29	110
500	16	13	17	49
1000	11	11	13	29
5000	7	9	10	13

Source: D14489S, p. iv.

Technology Cost

Based on a cost analysis performed at the U.S. Department of Energy's Hanford site, in Richland, Washington, PSVE was found to be a cost-effective method for remediation of soils containing lower concentrations of volatile contaminants. PSVE used on wells that average 10 standard cubic feet per minute (scfm) airflow rates was found to be more cost-effective than active soil vapor extraction for concentrations below 500 parts per million (ppm) by volume of carbon tetrachloride. For wells that average 5 scfm, PSVE is more cost effective below 100 ppm (D14489S, p. iii). For further details of this analysis, refer to Table 1.

Maintenance of a PSVE system is expected to cost 2% of the installed capital cost of the system per year. Operation and waste disposal costs are a function of concentration of contaminants and the airflow rate and will therefore vary widely (D14489S, p. 26). Once a system is installed, no utilities are generally required. If a valve and differential pressure control system are used, these could be run by solar-cell-powered batteries (D18119L, p. 384).

The PSVE technology has also been used by Idaho National Environmental Engineering Laboratory (INEEL) at radioactive waste management facilities to remove VOC-contaminated soil. Averaging the cost savings over 10 INEEL sites, PSVE yields a 59% cost savings, yielding a net cost savings of $3,450,000 (D19241Q, pp. 2, 4). Individual field demonstrations at the Hanford, INEEL, and Savannah River sites cost $2,909,000 (D19241Q).

Many applications for this technology utilize wells that already exist from previous soil vapor extraction operations. In these cases, costs are further reduced because the need to drill additional wells is negated.

Information Sources

D14489S, Enserch Environmental, 1994

D18119L, Rossabi et al., 1994

D19241Q, Office of Science and Technology, undated

T0593

Peat Technologies Corporation

MultiSorb 100 Adsorbent Media

Abstract

MultiSorb 100 adsorbent media is a new material, formed of granules of specially processed peat, and designed to be deployed in sorption columns. It is designed for adsorption of dissolved heavy

metals and organics from contaminated wastewaters. The MultiSorb 100 material was developed during 3 years of research by the University of Minnesota, Natural Resources Research Institute. This technology is not currently commercially available, but Peat Technologies Corporation is preparing to market it. MultiSorb 100 is most effective at influent concentrations of less than 500 parts per million (ppm). All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0594

PEAT, Inc.

Thermal Destruction and Recovery

Abstract
PEAT, Inc., has developed the thermal destruction and recovery (TDR) system for the treatment of medical, hazardous, and radioactive wastes. An electronic plasma heating system is used to break down wastes into three phases. The ceramic, metal, and off-gas phases can all be used as commercial products. The technology has been evaluated in treatability studies on infectious medical waste, Department of Defense (DOD) ammunition and energetic materials, U.S. Department of Energy (DOE) weapon components, ash, electronic scrap, batteries, asbestos, and organic compounds.

PEAT has constructed the pilot-scale TDR facility in Alabama and a commercial facility in Virginia. The TDR technology is patented and commercially available.

PEAT claims the following advantages of the TDR system:

- Resolves liability of hazardous wastes; no landfilling of final products is required.
- Processes wastes into economically valuable forms that may be recycled.
- Requires less space than a commercial incinerator, and the TDR system calls for much smaller off-gas equipment.
- Totally destroys any residual organic compounds, such as dioxins.
- May be permitted as a nonincinerator.
- Minimizes or eliminates preprocessing.
- Effectively destroys a wide variety of materials.
- Complies with proposed new air emissions standards.

As with other thermal treatment technologies, volatile metals will vaporize and be carried out of the unit with the airstream. The components of the reaction vessel often require frequent repair or replacement.

Technology Cost
Allied Technology Group (ATG) hired PEAT, Inc., to build a TDR system to treat mixed waste from the DOE's Hanford facility in Richland, Washington. The PEAT system will treat 250 lb of mixed waste per hour (D186838, p. 1). The total value of the DOE contract is $24 million and the TDR contract is worth $4.3 million. This calculates a treatment cost of approximately $\$4700/m^3$ of waste treated. At the other DOE sites, treatment costs for other vitrification technologies are estimated between $5600 and $\$6400/m^3$ (D186838, p. 1; D18248T, p. 55).

A report published by the Plasma Technology Subgroup of the Interstate Technology and Regulatory Cooperation (ITRC) Work Group in June 1996 estimated that treatment costs for a plasma arc unit would range from $50 to $1000 per ton (D19019M, p. 7). Most of the cost data for vitrification technologies are estimates based on pilot-scale operations. Such data are suspect because they are based more on extrapolation than on experience. Such estimates are difficult to compare because the assumptions on which they are based may vary widely (D18248T, p. 55).

Various other sources estimate vitrification costs from under $100/ton to over $1000/ton for units treating hazardous waste. These estimates are assumed to be for treatment only, not including pretreatment and disposal costs. The extreme variability of the costs may be attributable to differences in feed type and water content of the waste (D18248T, p. 55).

Many site-specific characteristics have an impact on the cost of vitrification technologies. One critical aspect of any thermal technology is the water content of the waste. Water dilutes feed material, requires energy to drive off, and physically limits the feed rate of waste. Feed preparation is another variable that differs with the technology and with site-specific characteristics. Many estimates do not take into account site preparation and waste disposal costs. Only complete treatment life-cycle assessments can provide reliable comparison data, and such studies are, by definition, highly site and waste specific (D18248T, p. 55).

Information Sources

D18248T, Sigmon and Skorska, 1998

D186838, Malloy, 1997

D19019M, Plasma Technologies, 1996

T0595

Peat/Compost Biofiltration — General

Abstract

Peat and compost biofilters are designed to treat vapor-phase organic contaminants. The peat or compost acts as the filter media upon which microorganisms attach, and then as the vapor-phase contaminants pass through the media, they are degraded by the microorganisms. This technology is often used for volatile organic compounds, and is an option for treating off-gas created by common remediation practices such as soil vapor extraction and air sparging.

Although the biofiltration technique using compost and peat media has been shown to be an efficient gas cleaning technology in Europe, the design and operational parameters, as well as the microbial processes involved, are still in the process of being defined. As a result, biofilters are not always readily predictable and are not necessarily operated at optimum conditions for the desired efficiency to be achieved.

This technology has been demonstrated in bench-, pilot-, and full-scale applications. The Bohn Biofilter Bohn off-gas treatment (T0130) is one example of a commercially available biofilter system that uses compost or soil as the filter medium.

This technology does not treat metals and is limited to treating contaminants that are susceptible to biodegradation by the microorganisms that are present in the biofilter media.

In some cases, contaminants can become sorbed onto the filter media. If this occurs higher readings may be observed for contaminant removal from the gas stream, however, the contaminants have not been degraded and the media itself becomes a process waste stream.

Technology Cost

A commercial vendor of biofiltration technologies that use soil or compost estimates the treatment cost with a biofilter at $5 to $10/kg of waste. Factors that have a significant effect on the unit price are the quantity of waste, the target contaminant concentration, and the initial contaminant concentration and the targeted final concentration of the treated contaminant. These

TABLE 1 Cost Comparison of Air Pollution Control Technologies (1991 U.S. dollars)

Technology	Total Cost ($) per 10^6 ft^3 of Air[a]
Incineration	130
Chlorine	60
Ozone	60
Activated carbon (with regeneration)	20
Biofiltration	8

Source: D14012V, Bohn, 1992.
[a]Costs obtained from B. Jaeger and J. Jeger, "Geruchsbekaempfung in Kompostwerken am Beispiel Heidelberg," Muell und Abfall, pp. 48–52 (Feb. 1978), and converted/updated to 1991 U.S. dollars.

price estimates do not always include all indirect costs (D10048R, p. 28). For more information on this particular technology, please see the summary of the Bohn biofilter (T0130).

According to this vendor, biofiltration is one of the most affordable air treatment technologies on the market (D14012V, p. 37). Table 1 compares the costs of various off-gas treatment technologies.

T0596

Pecan-Based Granular Activated Carbon (GAC) — General

Abstract

A method of converting pecan shells into an activated carbon media has been developed. Once converted, the pecan shell activated carbon can be used for removal of organics or metals from aqueous waste streams.

Pecan-shell-based granular activated carbon (GAC) has only been tested at bench-scale, and experiments are ongoing. The principal research institutions involved in this research are New Mexico State University and the Southern Regional Research Center, in collaboration with Louisiana State University.

Pecan shells are hard, high-density, low-ash materials. Researchers have suggested that producing GACs from pecan shells could be a cost-effective alternative to producing GACs from bituminous coal or lignite, the two most popular activated carbon precursors. Each institution has its own method for creating GAC from the pecan shells and both will be described in this summary.

Technology Cost

No available information.

T0597

Pedco, Inc.

Rotary Cascading Bed Incineration

Abstract

Rotary cascading bed incineration is an ex situ incineration technology that can treat organic- or hydrocarbon-contaminated materials such as sewage sludge, refinery sludge, coal tailings,

and spent foundry sand. This technology employs direct solids-to-gas contact established by lifting and cascading combustible solids through a hot-gas stream. Heat may be recovered after treatment for use in steam boilers.

This technology is protected under U.S. Patent 4,724,777 and U.S. Patent 4,563,246.

RIMS was unable to contact the vendor. The commercial availability of this technology is uncertain.

Technology Cost

No available information.

T0598

Pelorus EnBiotech Corporation

Slurry-Phase Bioremediation

Abstract

This is an ex situ, slurry-phase, biological remediation technology that treats soils contaminated with organics, particularly polycyclic aromatic hydrocarbons (PAHs) with four or greater rings.

In this process, the soil is mixed with water to obtain a pumpable slurry that is fed to a large-capacity continuously stirred tank reactor. The reactor is then supplemented with oxygen, nutrients, and, when necessary, a specific inocula of microorganisms to enhance the biodegradation process.

This bioslurry technique was originally developed and tested in the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration program by ECOVA Corporation. The technology is currently commercially available from Pelorus EnBiotech Corporation.

Technology Cost

No available information.

T0599

PerkinElmer, Inc.

NoVOCs

Abstract

NoVOCs™ is a patented, commercially available process to remove volatile organic compounds (VOCs) from groundwater. NoVOCs combines an air-lift pump with in-well aeration to remove contaminants in situ. A NoVOCs system includes a screened well submerged beneath the water table and an air line within the well that provides the air-lift pump effect. Contaminated water is pumped upward within the well by pressurized air. As the water is air-lifted, VOCs dissolved in the water volatilize from the aqueous phase into the vapor phase. Entrained vapors are then treated at the surface while the remaining deflected water percolates through the soil to the groundwater. Groundwater can then be treated through multiple cycles to achieve the desired level of contaminant removal.

PerkinElmer, Inc. (formerly EG & G, Inc.), reports that NoVOCs installations have treated sites contaminated with benzene, toluene, ethylbenzene, xylene, trichloroethene (TCE), tetrachloroethene (PCE), and petroleum hydrocarbons. The technology is unlike conventional pump-and-treat technologies in that it avoids the necessity of pumping water above ground for

treatment. However, it shares certain limitations of conventional pump-and-treat technologies, including difficulties in treating low-permeability formations and lower solubility contaminants. In addition, methods for determining site-specific circulation patterns around wells (i.e., the zone of treatment within an aquifer) are uncertain at this time.

Technology Cost

According to the vendor, the NoVOCs treatment process provides reduced capital costs, has minimum overhead and maintenance requirements, and eliminates disposal fees. PerkinElmer, Inc. (formerly EG & G, Inc.), indicates that in-well stripping is 20 to 40% less expensive than comparable in situ air sparging technologies and significantly less than pump-and-treat operations (D12781L). PerkinElmer also claims that NoVOCs is over 50% less costly than in situ biodegradation technologies when treating BTEX-contaminated groundwater (D16906W, p. 1). A detailed cost comparison of NoVOCs with other technologies is presented in Table 1.

Cost estimates in VISITT 4.0 range from $2 to $3/1000 gal. VISITT cost estimates do not always include all of the indirect costs associated with treatment, such as permits and treatment of residuals (D10141N, p.18).

An application of in-well vapor stripping (NoVOCs) for remediation of TCE in groundwater was conducted at Edwards Air Force Base in California between 1995 and 1996. Total expenditures for installation of the wells, assembly of the equipment, and operations and maintenance were approximately $600,000. An additional $217,000 was allocated for personnel, equipment, a trailer, and software (D188709, p. 4).

A NoVOCs system was tested for remediation of PCE in groundwater at a dry cleaning facility in Hutchinson, Kansas, in 1997. The NoVOCs system included a remediation well, an air diffuser, an infiltration gallery, and four monitoring wells. The field demonstration cost was approximately $95,000 (D188709, p. 28).

In 2000, cost estimates for the NoVOCs system were calculated based on a U.S. Environmental Protection Agency (EPA), Superfund Innovative Technology Evaluation (SITE) demonstration at North Island Naval Air Station in California. One-time capital costs for the NoVOCs system were estimated to be $190,000. Operational costs were an additional $160,000 for the first year and $150,000 for each additional year. Factoring in a 4% annual inflation rate, total costs are as follows: $350,000 for 1 year, $670,000 for 3 years, $1,000,000 for 5 years, and $2,000,000 for 10 years of operation. At the North Island site, a Thermatrix flameless oxidation system (T0795) was also used as part of the treatment train. The Thermatrix system cost an additional $989,000 (D21594L, pp. ES-8, ES-9).

Information Sources

D12781L, EG&G Environmental, date unknown

D10141N, VISITT 4.0

TABLE 1 NoVOCs Vendor-Estimated Cost Comparison (Normalized)[a]

Technology	TCE	BTEX[b]
NoVOCs with biofiltration	Not applicable	1
NoVOCs with activated carbon	1	1.5
Air sparging with SVE and activated carbon	2.5	1.9
In situ biodegradation	Not applicable	2.2
Pump and treat with air stripping and activated carbon	3	2.5

Source: Adapted from D16906W, p. 1.

[a] Normalized costs include capital and operation and maintenance over a 2-year period for NoVOCs, air sparging, and biodegradation, and a 5-year period for pump-and-treat methods.

[b] Benzene, toluene, ethylbenzene, and xylenes.

D16906W, EG&G Environmental, date unknown
D188709, U.S. EPA, 1998
D21594L, U.S. EPA, 2000

T0600

Perma-Fix Environmental Services, Inc.

Perma-Fix Process

Abstract

Perma-Fix Environmental Services, Inc. (Perma-Fix), has developed the Perma-Fix Process™ for the neutralization and stabilization of hazardous, radioactive, and mixed wastes. The Perma-Fix Process is a two-step treatment involving proprietary chemical treatment of wastes followed by the addition of stabilization chemicals to create a final waste form with the hazardous component of the wastes neutralized. The technology has been used commercially for several years.

Perma-Fix claims the following advantages of the Perma-Fix Process:

- Wastes are treated on-site, reducing transport costs.
- Process creates little or no volume increase.
- The hazardous component of the treated wastes is eliminated; treated wastes contaminated with metals may be disposed of as nonhazardous wastes, and mixed wastes may be disposed of as radioactive wastes, reducing disposal costs and liability concerns.
- Process effectively treats a variety of wastes, allowing clients to meet waste minimization targets required under federal regulations.

Technology Cost

In 1997, the vendor estimated that the cost of processing nonradioactive wastes averaged from \$150 to \$200 per barrel. For bulk processing of nonradioactive wastes, costs would be heavily site specific but would average \$200 per ton (personal communication: Dr. Louis Centofanti, President, Perma-Fix, March, 1997). At the U.S. Department of Energy's (DOE's) Fernald facility in Ohio, 22,000 lb of radioactive thorium nitrate was treated using the Perma-Fix Process at a cost of \$1.5 million (D18156Q, p. 18)

Information Source

D18156Q, Perma-Fix Environmental Services, Inc., 1998

T0601

Permeable Reactive Barriers — General

Abstract

Permeable reactive barriers (PRBs) are used for the in situ treatment of contaminated groundwater. The barriers are emplaced in the soil perpendicular to groundwater flow path of a contaminant plume. This allows the plume to move passively through the barrier, allowing the reactive media to precipitate, sorb, or degrade the contaminants. PRBs may contain metal-based catalysts for degrading volatile organics, chelators for immobilizing metals, nutrients and oxygen to encourage bioremediation, or other agents.

PRB technology has been used to treat groundwater contaminated with organic contaminants, inorganic contaminants, heavy metals, and radionuclides. The technology has been used in full-scale cleanups since 1995 and is commercially available through a number of vendors.

According to the U.S. Navy, PRBs have the following advantages:

- Passive, in situ treatment system for contaminated groundwater.
- Sites can remain productive during remediation efforts.
- Treatment conducted at roughly one fourth the cost of a pump-and-treat system.
- Low long-term operation and maintenance costs.
- Versatile system can treat many different types of contaminants.

PRBs have the following limitations:

- Clogging of the barrier due to biological or chemical precipitates may require maintenance.
- Complications during installation caused by above-ground structures and underground utilities.
- Geologic limitations such as the need for an aquiclude and the increasing costs as contaminant depth increases.
- Increased short-term capital costs for construction and installation when compared with pump-and-treat methods.

Technology Cost

For PRBs using elemental iron, the cost of the reactive media can be estimated based on a density of about 2.83 kg of media per meter and a cost of approximately \$440 to \$500 per ton. An installation cost between \$2500 and \$8000 per liter per minute of treatment capacity is a rule-of-thumb for estimating capital cost. Because the elemental iron treatment wall is patented, a site licensing fee, which is typically 15% of the capital costs (materials and construction), is often required. Operation and maintenance costs between \$1.30 and \$5.20 per 1000 liters of treated water may also be used as a rule-of-thumb estimate (D16068J).

Based on 1997 data, the estimated cost of a PRB system ranged from \$405,000, (corresponding to \$1400 per 1000 gal of groundwater extracted) to \$585,000, (corresponding to \$225 per 1000 gal of groundwater extracted). The capital costs ranged from \$373,000 to \$500,000 and operations and maintenance (O & M) costs ranged from \$32,000 to \$85,000. Treatment wall costs included system construction, installation, monitoring, and analytical costs. Costs may vary due to differences in the subsurface matrix, thickness, and composition of the wall. Data were provided by Geomatrix, the U.S. Navy, and the U.S. Coast Guard (D18882D, pp. 133, 145). Costs for several PRB deployments are given in Table 1.

Information Sources

D16068J, Vidic and Pohland, 1996

D18882D, Federal Remediation Technologies Roundtable, 1998

D206246, RTDF, undated web page

D20369A, RTDF, undated web page

D203689, RTDF, undated web page

D203703, RTDF, undated web page

D20628A, RTDF, undated web page

D20629B, RTDF, undated web page

D206224, RTDF, undated web page

D206304, RTDF, undated web page

TABLE 1 Permeable Reactive Barriers Field Deployments

Site (P = pilot)	Contaminants	Date	Cost
Nickel Rim, Sudbury, Ontario, Canada, mining	Ni, Fe, sulfate	1995	$30,000 design and installation
Elizabeth City, North Carolina, electroplating	Hexavalent chromium (Cr), TCE[a]	1996	$500,000 for design and installation
Hanford Site, Richland, Washington, nuclear reactor	Hexavalent Cr	1997	$480,000 for design and installation
Moffett Federal Airfield, Mountainview, California, solvents (P)	TCE, DCE[b], PCE[c]	1996	$100,000 for design, $365,000 for installation
Caldwell Trucking, New Jersey, industrial waste	TCE	1998	$1,120,000 for design and installation of two walls
Rheine, Westphalia, Germany, dry cleaner	PCE; 1,2-DCE	1998	$30,000 for design, $93,000 for installation
Federal Highway Administration Facility, Lakewood, Colorado	TCA,[d] TCE; 1,1-DCE; cDCE[e]	1996	$1,000,000 for design and installation
Fairfield, New Jersey, manufacturing site	1,1,1-TCA; PCE; TCE; DNAPL[f]	1998	$150,000 for design, $725,000 for installation
Coffeyville, Kansas, industrial site	TCA, 1,1,1-TCA	1996	$400,000 for installation
Central New York, industrial site	TCE, cDCE, vinyl chloride	1997	$797,000 for installation
Belfast, Northern Ireland, industrial site	TCE; 1,2-DCE	1995	$375,000 for installation
Watervliet Arsenal, Watervliet, New York, chemical storage (P)	PCE; TCE, cDCE, vinyl chloride	1998	$113,000 for design, $257,000 for installation
Portsmouth Gaseous Diffusion Plant, Piketon, Ohio, wastewater (P)	TCE	1996	$4,000,000 for installation

Source: Adapted from D20628A, D20629B, D203736, D203703, D203689, D20369A, D203747, D203725, D203714, D206246, D206111, D206304, D206224.

[a] TCE, trichloroethylene.
[b] DCE, dichloroethylene.
[c] PCE, perchloroethylene.
[d] TCA, trichloroethane.
[e] cDCE, cis-dichloroethylene.
[f] DNAPL, dense, non-aqueous-phase liquid.

D206111, RTDF, undated web page

D203714, RTDF, undated web page

D203725, RTDF, undated web page

D203747, RTDF, undated web page

D203736, RTDF, undated web page

T0602

Pet-Con Soil Remediation, Inc.

Thermal Desorption

Abstract

Pet-Con Soil Remediation, Inc. (Pet-Con), offers a low-temperature thermal desorption off-gas treatment technology that uses heat to volatilize organic contaminants to remediate contaminated soil. The technology uses a combination of a low-temperature primary treatment chamber and a secondary high-temperature treatment chamber. The technology has been used to remove gasoline and diesel fuel from contaminated soil. According to information supplied by the vendor in 1995, the technology has been used for 23 full-scale cleanups. RIMS were unable to contact the vendor.

The vendor claims that its thermal desorption technology offers quick turnaround time, terminates future liability, and processes virtually all soil matrices at a competitive price.

Only soils contaminated with light petroleum distillates can be treated by this technology. Frozen soil is difficult to process.

Technology Cost

In 1995, Pet-Con estimated that treating contaminated soil using its thermal desorption technology would cost between \$27 and \$45 per ton. This estimate stated that price estimates may not include all indirect costs associated with treatment, such as excavation, permits, and treatment of residuals. Factors listed as having a significant effect on cost include (in decreasing order of importance: utility/fuel rates, labor rates, mobilization/demobilization costs, waste handling and preprocessing costs, the characteristics of the soil, the moisture content of the soil, site preparation costs, quantity of waste, costs of excavation below the water table, the initial contaminant concentration, the amount of debris associated with the waste, and the depth of the contamination (D10398A, p. 23).

Information Source

D10398A, VISITT 4.0, 1995

T0603

Petro-Green, Inc.

Petro-Green ADP-7

Abstract

Petro-Green, Inc., ADP-7 is a biodegradable, water-soluble, nonionic/anionic liquid surfactant concentrate that emulsifies hydrocarbons, makes them water-wet, and allows natural processes to biodegrade them in situ. Once it is an emulsion, the hydrocarbons are no longer flammable or odoriferous. ADP-7 promotes the natural biodegradation processes.

This product can be directly applied to leaks and spills of gasoline, crude oil, diesel, and other hydrocarbons, then flushed with water. It may also be applied to older hydrocarbon-soaked soils or surfaces.

According to the vendor, major oil companies have been using ADP-7 for over 15 years to clean up crude oil leaks on the ground at oil fields. Several fire departments also use ADP-7 to clean up gasoline and diesel leaks at auto accident sites. This product is currently in use and is commercially available.

Technology Cost
Petro-Green ADP-7 is available in 6-gal pails at a cost of $84.50 each, including delivery. It is also available by the drum for treating larger areas of contamination. According to the vendor, 1 gal of ADP-7 should be applied for every 25 to 35 gal of hydrocarbons (D17716W, p. 5).

Information Source

D17716W, Petro-Green, Inc., 1998

T0604

Philip Environmental Services Corporation

Thermal Recycling System

Abstract
The thermal recycling system (TRS) is a thermal desorption unit designed for the on-site, ex situ remediation of mercury from contaminated soils. The system volatilizes and then condenses mercury for recovery. The TRS processes contaminants in a nonreactive atmosphere. It uses indirect heat sources to desorb contaminants and recovers 90% of the contaminants.

The TRS could potentially treat nonmunicipal sludge, slag, or natural sediment ex situ. In addition to mercury, the system could be used to treat polychlorinated biphenyls (PCBs), petroleum hydrocarbons, dioxins/furans, and chlorinated solvents.

The unit uses a fluidized bed in the processing chamber. Particles entering the chamber need to be less than 0.25 inch in diameter.

Philips is not currently marketing the TRS. This summary is included in RIMS without the express approval of Philips.

Technology Cost
No available information.

T0605

Physical Sciences Inc.

Metals Immobilization and Decontamination of Aggregate Solids (MeIDAS)

Abstract
The metals immobilization and decontamination of aggregate solids (MeIDAS) technology was developed to treat organics and heavy metals in soils, sediments, and sludges. It has not progressed beyond a pilot-scale study and is not commercially available.

The MeIDAS technology is a modified incineration process in which high temperatures destroy organic contaminants in soil and concentrate metals into fly ash. Details of the metals immobilization process can vary based on the specific application, but the essential steps are to combine the toxic-metal containing material with the appropriate amount of sorbent, to form this mixture into pellets or briquets placing the metal compounds into intimate contact with the sorbent, and to heat treat the pellets causing a reaction to form nonleachable metal compounds. The MeIDAS process requires a sorbent.

Technology Cost
No available information.

T0606

Phytokinetics, Inc.

Phytoremediation

Abstract
Phytokinetics, Inc., is a company that designs and implements phytoremediation strategies for treating contaminants in soil, groundwater, and wastewater. These treatment strategies often involve rhizodegradation, a process that uses microbes in the root zone to degrade contaminants. The Phytokinetics technologies also incorporate other plant processes, such as phytoextraction, phytotransformation, phytostabilization, phytovolatilization, and evapotranspiration. Along with rhizodegradation, these processes can destroy a variety of contaminants including chlorinated solvents, explosives, heavy metals, pesticides, petroleum hydrocarbons, and wood preservatives.

According to the vendor, the Phytokinetics technologies have the following advantages over traditional remediation methods:

- Costs are lower.
- The aesthetics of a site are often improved.
- Public acceptance is high.
- Marketable goods (e.g., pulp and paper products) can be produced from the vegetation.

A primary limitation of phytoremediation is that it takes time, and several growing seasons may be required to achieve treatment goals. Phytoremediation is also limited by the depth of the roots. The contaminants to be treated must reside in the top 3 to 6 ft of soil; or, in the case of groundwater, the water table can be no more than 10 ft below ground surface. The creation of a process waste stream may also be seen as a limitation. In cases where the plant takes up and stores the contaminant, the plant may be considered a hazardous waste (depending on the contaminant type and concentrations in the plant matter).

Technology Cost
The vendor estimates that phytoremediation could cost less than $200 per ton of soil contaminated with petroleum hydrocarbons, and less than $2 per 1000 gal of groundwater contaminated with organics (D17085o). For other organic contaminants, costs of phytoremediation may range from $200 to $600 per ton. Costs are heavily dependent on site characteristics. The vendor states that because phytoremediation uses the same equipment and materials common to agricultural practices, it is possible to equate the costs of remediation to local costs for planting crops (in some cases). At industrial sites, the soil may be compacted and devoid of vegetation. Such sites could take extensive preparation before sustainable plant growth would be possible (D177600, p. 11).

For a one-acre site, the vendor estimates costs will range from $2000 to $5000. This estimate includes site preparation, planting, and removal (harvest) of plant material. The vendor states that an ancillary benefit of phytoremediation is that the site could, in principle, be used for agriculture (D177600, p. 11).

At a site in Texas where a Phytokinetics, Inc., technology has been proposed, projected costs are $390,000. Groundwater at the 22-acre site is contaminated with salts and heavy metals. Cleanup would involve planting eucalyptus and salt cedar trees. Projected costs include expenses associated with greenhouse studies, field trials, and a full-scale application (D22474I, p. D-5).

Because phytoremediation utilizes solar energy, the technology requires few energy inputs. This factor reduces operating costs. Expenses are also spread out over a greater time period than other technologies because phytoremediation is a slower treatment process. The result is lower annual costs. Frick et al. note that “agronomic costs, including planting, tillage, fertilization, and harvesting, can be insignificant in comparison with associated administrative costs, such as site management, regulatory reporting, and analysis of data" (D20756H, pp. 42, 43).

Information Sources

D120661, Idaho National Engineering Laboratory, 1996
D17085O, Phytokinetics, Inc., 1997
D177600, Phytokinetics, Inc., 1998
D20756H, Frick et al., 1999
D22474I, ITRC, 2001

T0607

Phytoremediation — General

Abstract
Phytoremediation is an emerging technology that uses plants and their associated rhizospheric microorganisms to remove, degrade, or contain contaminants. The technology is used to treat contaminants in soils, sediments, groundwater, surface water, and even the atmosphere. Phytoremediation has been used to treat a variety of environmental contaminants, including volatile organic compounds (VOCs), petroleum and aliphatic hydrocarbons, polychlorinated biphenyls (PCBs), chlorinated solvents, pesticides, metals, radionuclides, explosives, and excess nutrients.

Although phytoremediation is a relatively new concept, techniques and theories developed through the application of well-established agroeconomic (farming) technologies are easily transferable. Plants have been used for more than 300 years to treat wastewater. In addition, plant-based remediation methods for slurries of dredged material and soils contaminated with metals have been proposed since the mid-1970s. Extensive research is being conducted on many aspects of phytoremediation, and several vendors offer field-tested, commercially available technologies.

Phytoremediation has the following advantages:

- The technology operates in situ and is solar driven.
- Costs are approximately 20 to 30% of costs associated with mechanical treatments.
- The technology has high public acceptance.
- The technology is applicable to many remediation scenarios including large contaminated surface areas.

Some potential disadvantages associated with phytoremediation/plant-assisted remediation techniques include the following:

- Treatment is generally limited to soils within 3 ft of the surface and groundwater within 10 ft of the surface.
- Treatment time is relatively long (usually more than one growing season).
- Climatic or hydrologic conditions may restrict the growth rate of certain plants.
- Contaminants may enter the food chain via animals or insects that consume plant material containing contaminants.

Technology Cost
The U.S. Environmental Protection Agency (EPA) notes that the most significant phytoremediation costs are expenses common to other remediation methods. These costs include activities

associated with site characterization, treatability studies, full-scale design, construction, operation, maintenance, and monitoring (D22523A, p. 20). According to the Interstate Technology and Regulatory Cooperation (ITRC) Work Group, phytoremediation does have several cost components that are unique to the technology. These components often include the following:

- Plant or tree stock and/or seeds
- Fertilizers, pesticides, and additional soil amendments
- Agricultural equipment for amendments application, tilling, and/or harvesting
- Irrigation equipment and a water source
- Tubes for stimulating deep root growth (collars)
- Pest control devices
- Supplies, equipment, and/or analyses for testing plant tissues and environmental conditions
- Flow control devices
- Plant litter collection, maintenance, pruning, mowing, and/or harvesting
- Disposal of plant wastes (D22474I, p. 59)

Because phytoremediation utilizes solar energy, the technology requires few energy inputs. This factor reduces operating costs. Because phytoremediation is a slower treatment process, expenses are also spread out over a greater time period than other technologies. The result is lower annual costs. Frick et al. also note that “agronomic costs, including planting, tillage, fertilization, and harvesting, can be insignificant in comparison with associated administrative costs, such as site management, regulatory reporting, and analysis of data” (D20756H, pp. 42, 43).

Phytoremediation technologies generally cost 10 to 20% as much as mechanical treatment technologies (D20213R, p. 2). However, phytoremediation costs are dependent on treatment strategy. For example, harvesting plants that bioaccumulate metals can drive up the cost of treatment compared to techniques that do not require harvesting (D177815, p. 6).

Table 1 presents a cost comparison between phytodegradation and pump-and-treat methods. Tables 2, 3, and 4 compare cost estimates for phytoremediation with estimates for other treatment technologies. Because these values are often based on bench- or pilot-scale data, the information should be viewed with caution.

Cost estimates for phytoremediation vary widely. One estimate for phytoextraction included \$10,000 per acre for planting, with total remediation costs estimated at \$60,000 to \$100,000 per acre. Total costs included expenses associated with maintenance, monitoring, and verification testing. Another estimate placed phytoremediation costs at \$80/yd^3 of contaminated soil (D131431). Cleanup costs for an acre of metal-contaminated soil were estimated to range from \$60,000 to \$100,000. This estimate assumes remediation to a depth of 50 cm. In contrast, excavation and disposal storage without treatment for a comparable site would cost at least \$400,000 (D16482T).

Removing radionuclide contamination from water using sunflowers was estimated to cost between \$2 to \$6 per 1000 gal of water treated. These costs include waste disposal and capital expenses (D131431).

Phytoremediation was estimated to cost approximately \$3500/kg of waste treated at a site contaminated with benzene, toluene, ethylbenzene, and xylene (BTEX); chlorinated solvents; and other volatile organic compounds. Total savings associated with using phytoremediation at the site instead of conventional pump-and-treat strategies were estimated to be \$13 million over the course of the project (D186678, p. 29).

For treating pesticide-contaminated sites, phytoremediation costs are approximately \$80/yd^3, or \$60,000 to \$100,000 per acre. These costs are generally lower than the costs of alternative technologies used to treat pesticides, such as low-temperature thermal desorption (\$100 to

TABLE 1 Cost Comparison between Phytodegradation Using Hybrid Poplar Trees and a Conventional Pump-and-Treat Method (3 Wells and Reverse Osmosis System)

Method/Cost Component	Cost
Phytodegradation	
Design and implementation	\$50,000
Monitoring equipment	
Capital	\$10,000
Installation	\$10,000
Replacement	\$5,000
5-Year Monitoring	
Travel and administration	\$50,000
Data collection	\$50,000
Reports (annual)	\$25,000
Sample analysis	\$50,000
Total	\$250,000
Pump and Treat	
Equipment	\$100,000
Consulting	\$25,000
Installation/Construction	\$100,00
5-Year Costs	
Maintenance	\$105,000
Operations (Electricity)	\$50,000
Waste disposal	\$180,000
Waste disposal liability	\$100,000
Total	\$660,000

Source: Adapted from D22474I.

TABLE 2 Cost Comparison between Phytoremediation and Other Remediation Technologies

Contaminant	Phytoremediation Costs	Costs for Other Technologies
Metals	\$80/yd^3	\$250/yd^3
Petroleum hydrocarbons	\$70,000	\$850,000
10 acres lead-contaminated land	\$500,000	\$12 million
Solvents in groundwater (2.5 acres)	\$200,000 (installation and initial maintenance costs)	\$700,000 (annual operating costs)
Radionuclides in surface water	\$2 to \$6 per 1000 gal treated	None listed
1 hectare to 15 cm in depth (various contaminants)	\$2,500 to \$15,000	None listed

Source: Adapted from D177815 and D22523A.

TABLE 3 Cost Comparison between Phytoextraction of Metals and Other Treatment Options

Treatment Type	Cost per Cubic Meter	Time Required (Months)	Additional Factors/ Expenses	Safety Issues
Phytoextraction	\$15–\$40	18–60	Time/land commitment	Residue disposal
Fixation	\$90–\$200	6–9	Transport/excavation, long-term monitoring	Leaching
Landfilling	\$100–\$400	6–9	Long-term monitoring	Leaching
Soil extraction and leaching	\$250–\$500	8–12	5,000-m^3 minimum chemical recycle	Residue disposal

Source: Adapted from D22474I.

TABLE 4 Cost Comparison between Phytoremediation (Enhanced Rhizosphere Bioremediation) and Other Treatment Options

Treatment Type	Cost Range per Ton
Phytoremediation	\$10–\$35
In situ bioremediation	\$50–\$150
Soil venting	\$20–\$220
Indirect thermal	\$120–\$300
Soil washing	\$80–\$200
Solidification/stabilization	\$240–\$340
Solvent extraction	\$360–\$440
Incineration	\$200–\$1,500

Source: Adapted from D22474I.

\$400/yd^3) and incineration (\$300 to \$1000/yd^3). In contrast, bioremediation costs at pesticide-contaminated sites can be as low as \$8.40/yd^3 (significantly less than phytoremediation), or as high as \$197/yd^3 (over twice as much as phytoremediation) (D21486I, p. 6).

Information Sources

D131431, GWRTAC, 1996

D16482T, U.S. EPA Recent Developments for In Situ Treatment of Metal-Contaminated Soils, 1997

D177815, U.S. EPA, 1997

D186678, Sumner and Boyajian, 1998

D20213R, U.S. EPA, 1997

D20756H, Frick et al., 1999

D21486I, Frazar, 2000

D22474I, ITRC, 2001

D22523A, U.S. EPA, 2001

T0608

Phytoremediation: Hyperaccumulation — General

Abstract
Phytoremediation is an emerging bioremediation technology that uses plants to treat contaminated media. Hyperaccumulation is a specific type of phytoremediation that can be used at sites contaminated by radionuclides and heavy metals. Hyperaccumulation is defined as the ability of a plant to absorb and store more than 2.5% of its dry weight in heavy metals without experiencing a reduction in yield. Plants, which are grown in contaminated soil or water, assimilate the contaminants through a process known as translocation. In this process, contaminants are absorbed by the root system and moved to the above-ground parts of the plants (i.e., the stems and leaves). The above-ground parts of the plant are then harvested and removed from the site.

Researchers and technology vendors state that hyperaccumulation technologies have several advantages over traditional heavy metal and radionuclide removal methods. Collecting and disposing of the contaminated plant material can allow for significant volume reductions when compared to the excavation of contaminated soils. Hyperaccumulation may also allow for more rapid remediation of sites currently awaiting cleanup. In addition, the plants can act as a ground cover during technology application, and the process can leave treated topsoil in a more useful condition than some alternative technologies.

The vegetation used to extract toxic metals may pose a risk to animals that consume these plants. Animal consumption of process plants could also result in harmful metals working their way up the food chain. Hyperaccumulation is a much slower process than most chemical and physical technologies, and its performance is typically measured in months or years. Technology effectiveness is limited by root growth; thus, wastes must be relatively close to the surface. In addition, the toxicity of the targeted contaminants and other site-specific characteristics such as pH, soil characteristics, nutrient content, and water availability can impact technology performance.

Technology Cost
Because phytoremediation utilizes solar energy, this group of technologies (including hyperaccumulation) requires few energy inputs. Therefore, energy costs are often lower than the costs associated with alternative technologies. Because phytoremediation is a slower treatment process, expenses are also spread out over a greater time period than other technologies. The result is lower annual costs. Frick et al. also note that "agronomic costs, including planting, tillage, fertilization, and harvesting, can be insignificant in comparison with associated administrative costs, such as site management, regulatory reporting, and analysis of data" (D20756H, pp. 42, 43)

Because hyperaccumulation typically involves the harvesting of plants, treatment costs can be higher than phytoremediation technologies that do not require vegetation removal and disposal (D177815, p. 6; D21292A, p. 14). However, the hyperaccumulating plants used in remediation applications may have some value. Plants containing high percentages of metals can be burned, and the metals can be recovered from the ash. Valuable metals can then be sold, possibly offsetting part of the remediation costs (D11887Q).

The U.S. Environmental Protection Agency (EPA) claims that the 30-year cost of treating lead at a 12-acre site using phytoextraction (a technology involving the extraction of metals, radionuclides, or certain organic compounds by direct uptake into plant tissue) would cost approximately $200,000. In contrast, the EPA estimated that excavation and disposal would cost $12,000,000, soil washing would cost $6,300,000, and soil capping would cost $600,000. For a 1-acre site with thick sandy loam, phytoextraction technologies are estimated to cost between $60,000 and $100,000. This estimate assumes treatment to a depth of 20 inches (D21292A, p. 17).

According to the Interstate Technology and Regulatory Cooperation (ITRC) Work Group, Edenspace's phytoremediation technology (a technology involving hyperaccumulation) was applied at a site in Trenton, New Jersey, for approximately $150,000. This project, which was part of the U.S. EPA's Superfund Innovative Technology Evaluation (SITE) program, involved treating over one acre of lead-contaminated soil. Soil was treated to a depth of 12 inches (D22474I, p. D-3; D18278Z, p. 422).

Edenspace Systems Corporation's phytoremediation technology was also used at a DaimlerChrysler facility in Detroit, Michigan, to reduce lead concentrations in 5700 yd^3 of soil (D19875I, p. 1). According to the vendor, initial lead concentrations in soils ranged from 75 to 3490 mg/kg. Final concentrations of 900 mg/kg were achieved after one growing season (D225138, pp. 12, 13). Technology costs were reported to be $400,000, representing cost savings of approximately $1 million over alternative treatment methods (D22517C, p. 1).

According to an article published by the National Wildlife Federation, Edenspace's phytoextraction method removed uranium at the Aberdeen Proving Ground for one-tenth the cost of traditional treatment technologies. These traditional technologies were reported to be as high as $1 million per acre (D22515A, p. 2).

Phytotech, Inc. (now owned by Edenspace), states that the rhizofiltration of aqueous wastes using sunflowers would average $2 to $6 per 1000 gal of waste treated, including disposal costs (D193924, p. 1). The vendor also claims that phytoremediation is 15 to 25% less expensive than alternative methods used to treat sites contaminated with lead (D19877K, p. 1). According to Phytotech, the costs for treating lead-contaminated sites in 1998 were approximately $400/$yd^3$ (D205334, p. 4). Another estimate places soil treatment costs using the Phytotech technology at $25 to $50 per ton (D20331W, p. 46).

Information Sources

D11887Q, Boyd, 1996
D177815, U.S. EPA, 1997
D18278Z, Flathman and Lanza, 1998
D193924, Wilke, 1997
D19877K, Edenspace, undated web site
D19875I, Edenspace, 1999
D20331W, Naval Facilities Engineering Service Center, 1998
D205334, U.S. DOD, 1998
D20756H, Frick et al., 1999
D21292A, U.S. EPA, 2000
D22474I, ITRC, 2001
D225138, Blaylock, 2000
D22515A, Bower, 2000
D22517C, Helman, 2001

T0609

PhytoWorks, Inc.

Mercury Removal Using Genetically Engineered Plants

Abstract

A new phytoremediation technology is being developed for treating heavy-metal-contaminated soils. Researchers at the University of Georgia have modified two bacterial genes, *merA* and *merB*, and inserted them into the deoxyribonucleic acid (DNA) of certain plants, enabling them

to remove mercury from soil. The mercury from the soil is transformed into gaseous metallic mercury by the plant and released into the atmosphere. The plants may treat contaminated soils in situ or the soil can be moved to another location for ex situ treatment.

This technology is currently being developed in the laboratory, and no field studies have been conducted. The University of Georgia holds patents on these engineered plants, and PhytoWorks licenses the technology from the University.

Phytoremediation has the following advantages:

- The technology involves little environmental disturbance.
- Few energy inputs are required since the process is driven by solar energy.
- The technology is more cost effective for treating large areas than alternative technologies.
- Several plant species can be used simultaneously to treat a variety of contaminants at a given site.
- Basic agricultural techniques are used.
- The technology has a high level of public acceptance.

Several limitations do exist. The mercury vapor released into the atmosphere could be transported to aquatic systems, creating problems for fish and other wildlife. Phytoremediation is only effective at shallow depths since root density decreases with depth. The mobility of contaminants also decreases with depth. In addition, phytoremediation is a slower process than alternative technologies, and cleanup often requires several growing seasons. Environmental factors, including soil type, water availability, temperature, nutrients, and solar radiation can also limit the success of phytoremediation.

Technology Cost

The PhytoWorks technology is not yet commercially available, so cost information is not available. It has been suggested, however, that these genetically altered plants may offer a cost-effective alternative to other heavy-metal remedial technologies such as electrolytic treatment, chemical leaching, in situ mobilization, and vitrification (D13016V, p. 3186). One 1998 estimate is that the cost of phytoremediation for mercury-contaminated soil and groundwater is likely to be a fraction of the cost of landfilling, thermal treatment, or chemical extraction (D18278Z, p. 424).

According to the developer, up-front capital costs are minimal because no new equipment needs to be purchased or installed (D18767B, p. 17). Implementation is also inexpensive since it uses basic agricultural techniques (D18767B, p. 17).

General cost estimates for phytoremediation range from \$3 to $\$100/m^3$. The annual costs of using phytoremediation in a cropping system is approximately \$0.02 to $\$1.00/m^3$. These annual costs are significantly less than the costs associated with alternative remediation technologies (D20756H, p. 42).

Because phytoremediation utilizes solar energy, the technology requires few energy inputs. This factor reduces operating costs. In addition, expenses are spread out over a greater time period than other technologies since phytoremediation is a slower treatment process. The result is lower annual costs. Frick et al. also note that “agronomic costs, including planting, tillage, fertilization, and harvesting, can be insignificant in comparison with associated administrative costs, such as site management, regulatory reporting, and analysis of data” (D20756H, pp. 42, 43).

Information Sources

D13016V, Rugh et al., April 1996

D18278Z, Flathman and Lanza, 1998

D18767B, Boyajian and Suner, 1998

D20756H, Frick et al., 1999

T0610

Pile Biodegradation (Biopile) — Multiple Vendors

Abstract

Biopile is an ex situ bioremediation technology. It involves placing contaminated soils into piles or cells above ground, and stimulating aerobic or anaerobic microbial activity within soils through controlled aeration. Air is supplied to the biopile via a pipe-and-pump system, which either forces air into the pile (positive pressure) or draws air through the pile (negative pressure). Forcing air into the pile helps maintain constant temperature and aerobic conditions, while drawing air out of the pile can create anaerobic conditions. Although composting systems require large amounts of nutrients and bulking agents, fewer additives are needed for biopiles. Biopiles are normally operated at lower temperatures since less organic material is added.

The biopile technology is commercially available through several vendors. It has been used at sites across the United States to treat soils contaminated with light hydrocarbons such as gasoline, diesel fuel, heating oil, light crude, and used oils. According to one vendor, the use of a vacuum source to draw air through the treatment system facilitates control and treatment of volatile compounds in the off-gas. In addition, the leachate from the treatment system is recovered and recycled, thus eliminating the need for disposal of potentially contaminated water.

Biopiles have some potential limitations. For example, certain chemicals such as polychlorinated biphenyls and other hydrocarbons are resistant to biodegradation. In addition, high concentrations of toxic metals, such as lead, copper, and mercury, may limit treatment using biopiles.

Technology Cost

Biopile costs primarily depend on the contaminant type, the contaminant concentration, and the soil's grain size (D11809C, p. 2). Other factors that influence cost include the quantity of media being treated, the capital costs of the system used, labor expenses, and transportation expenses (D21349A, p. 2). The average cost of treatment for gasoline-contaminated soil varies between $25 and $65 per ton. Soils contaminated with heating oil may be treated at a cost of $55 to $85 per ton. These costs include soil excavation, treatment, and environmental monitoring (D11809C, p. 2).

As part of a pilot study, the biopile technology was tested at the Marine Corps Mountain Warfare Training Center in Bridgeport, California. The site was contaminated with total petroleum hydrocarbons (TPH) at concentrations of 1200 parts per million (ppm). After 2 months of treatment using biopile, TPH concentrations were reduced to 120 ppm. Costs for this project were $80 per ton of soil treated (D21224Y, p. 23).

The biopile process was used at brownfield site in Hackensack, New Jersey. This site was contaminated with TPH at concentrations averaging 18,000 ppm. Twenty-two thousand cubic yards of soil at the site were treated, and final TPH concentrations were less than 1000 ppm. The cost for this project was $500,000, which was less than the $10 million estimate for using an alternative treatment technology (D21947Q, pp.3, 4).

At a brownfield site in Illinois, the biopile process was used with air sparging to treat soils contaminated with petroleum hydrocarbons and by-products of asphalt production. Treatment at the 13- to 15-acre site occurred for one year, and site closure was achieved as a result of the process. The project cost was approximately $100,000, which was significantly less than the estimated cost of landfilling the contaminated soil (D21948R, pp. 3, 5).

General cost estimates for Battelle's biopile technology range from $30 to $100/yd^3 (D21349A, p. 2). Although these estimates include the costs of preprocessing wastes, they exclude expenses associated with excavation, permitting, and disposal (D21349A, p. 4). Battelle's biopile process was used in a field demonstration to treat approximately 500 yd^3 of soil contaminated with petroleum hydrocarbons and benzene, toluene, ethylbenzene, and xylene (BTEX). Total costs for this demonstration were $88,000, or $176/yd^3 of soil treated. Data analysis and generation of a report accounted for a significant amount of project costs (D21349A, pp. 7, 8).

According to the Canadian SEDTEC Report, the Biogenie biopile process costs between \$30 and \$50 per metric ton of soil treated. The Biogenie process is designed to treat polycyclic aromatic hydrocarbons (PAHs), petroleum hydrocarbons, oil and grease, volatile organic compounds (VOCs), halogenated organics, BTEX, and explosives (D195362, p. 1).

Treatment of explosives-contaminated soil using stage one of Waste Management, Inc.'s, two-stage static soil process (TOSS) is approximately \$110/yd^3. If stage two is necessary, the cost increases to \$254/yd^3 (D194676, pp. 36, 37). For more information on the TOSS process, please refer to the technology overview.

Information Sources

D11809C, EnviroAccess, May, 1995

D194676, Jerger, 1999

D195362, SEDTEC Report, 1996

D21349A, U.S. EPA, undated

D21947Q, U.S. EPA, undated

D21224Y, U.S. DOE, 1996

T0611

Pintail Systems Inc.

Spent-Ore Bioremediation Process

Abstract

Pintail Systems, Inc.'s, spent-ore bioremediation technology includes two main treatment processes. The first process involves the biological treatment of cyanide wastes using indigenous bacteria, which are isolated from contaminated sites and cultured in large quantities for full-scale applications. The second process involves metal biomineralization in which biological processes are adapted to immobilize soluble and leachable metals.

Full-scale demonstrations of Pintail Systems, Inc.'s, spent-ore bioremediation process have been conducted at a number of mine sites in the United States. The first full-scale demonstration of the process for cyanide detoxification in a spent-ore heap was performed at the Yellow Pine Mine near Yellow Pine, Idaho, in 1992. In addition, the technology has been used at sites in Mexico and Canada. This technology and several similar bioremediation processes are commercially available through the vendor. Pintail Systems, Inc., is also working with Sub-Surface Waste Management, Inc. (a subsidiary of U.S. Microbes, Inc.), to further apply its bioremediation technologies in the United States, as well as in Europe and Asia.

According to the vendor, the spent-ore bioremediation process has the following advantages over other treatment technologies:

- Treats all forms of cyanide.
- Offers better treatment efficiency than chemical treatment methods.
- Simultaneously reduces concentrations of cyanide and other common inorganic contaminants.
- Improves revegetation potential.

The spent-ore bioremediation technology involves biological processes that are both site specific and waste specific. Therefore, the technology must be engineered and tested for each site and for each waste stream treated. Large variations in contaminant concentrations could

negatively impact the microorganisms involved in the treatment process. In addition, low temperatures (less than 45°F) and high temperatures (greater than 85°F) may also inhibit treatment rates.

Technology Cost

According to the vendor, Pintail Systems, Inc.'s, bioremediation processes are less expensive than engineered technologies because the majority of the Pintail methods are in situ. For ex situ applications, the construction of bioreactors accounts for the greatest costs. The vendor claims that the following factors reduce costs compared to alternative technologies:

- No complicated waste handling or removal is required (although process by-products may require additional treatment or disposal).
- Materials (often involving only microorganisms and micronutrients) and application methods are inexpensive.
- The recovery of precious metals from process by-products may serve to off-set treatment costs in some applications (D22454E, p. 1; D22456G, pp. 3, 4).

Information Sources

D22454E, Pintail Systems Inc., undated

D22456G, U.S. EPA, 2000

T0612

Plasma Environmental Technologies, Inc.

Plasma Arcing Conversion (PARCON) Unit

Abstract

The Plasma Arcing Conversion (PARCON) technology is a proprietary treatment method that involves a three-step process of thermal decomposition, oxidation, and neutralization. The technology is primarily suited to treat liquids and soils contaminated with pesticides, metals, and organic compounds. PARCON was originally designed and manufactured in Hungary at the country's research institute, Villamosipari Kutato Intezet (VKI). In 1998, the technology was licensed exclusively to the Canadian company Plasma Environmental Technologies, Inc., for commercialization in North America, South America, and Asia. Plasma Environmental Technologies has subsequently granted sublicenses to additional vendors.

According to Plasma Environmental Technologies, the PARCON 125 unit has the following advantages:

- A variety of contaminants can be treated, and multiple contaminants can be treated simultaneously.
- Destruction and removal efficiencies (DREs) for contaminants are high and consistent; emissions of harmful by-products are minimal.
- The unit can be combined with other units to increase treatment capacity or integrated into a treatment train with other technologies.
- The unit is relatively small and easy to transport; using it on-site also reduces the risks associated with transporting waste off-site for treatment or disposal.
- It is easy and safe to operate; system tear-down and cleanup is also fast and safe.

Plasma technologies have traditionally been very expensive. In addition, research indicates that the PARCON technology may produce potentially toxic by-products when processing chemical agents or energetics (although the vendor claims these by-products are less hazardous than target contaminants and the amounts produced are fairly small).

Technology Cost

According to the vendor, plasma systems are less expensive than retrofitting existing incinerators or building new facilities that have to meet current regulatory standards (D22574L, p. 11). PARCON 125 units cost approximately $500,000. The cost per unit treated is currently unavailable (personal communication, Colin Andrews, Plasma Environmental Technologies, Inc., July 1997).

Information Source

D22574L, Plasma Environmental Technologies, Inc., 2000

T0613

Plasma Vitrification — General

Abstract

Vitrification is the process of converting materials into a glass or glasslike substance. Vitrification allows for the treatment of many different kinds of waste and produces a final waste form that typically is durable and leach resistant. During the process of thermal vitrification, organic contaminants are typically destroyed, and inorganic materials are melted.

Many vitrification technologies operate using plasma, an ionized gas to melt wastes. At high temperatures, electrons are stripped of their nuclei and the matter exists as a mixture of negative electrons, positive nuclei, and atoms. The ionized particles allow plasma to be an excellent conductor of heat and electricity. Plasma vitrification technology is commercially available in the United States and internationally.

Plasma technologies are able to achieve higher temperatures than conventional Joule-heated systems, which use electric resistance heating to melt waste materials. Plasma systems also allow for higher power densities than Joule-heated systems. Joule-heated systems are discussed in RIMS technology T0452.

Vitrification has four major advantages over other methods of waste management. The primary advantage is the durable final waste form glass produced. In most cases, the glass performs exceptionally well in leach tests. Because of the chemical and physical durability of the produced glass, it has been considered for recycling as aggregate or other products. The second major advantage of vitrification is the flexibility of the waste glass in incorporating a wide variety of feed materials, without markedly diminishing the quality of the glass. The third advantage of vitrification is the ability to process both organic and inorganic wastes. Lastly, vitrification may result in a significant volume reduction of the treated waste.

Vitrification's main limitation is that it is extremely energy intensive, and thus, may be more expensive than other remedial technologies. A second major limitation is the potential for some contaminants (organic and inorganic) to volatilize during treatment. These limitations may be amenable to modification of process parameters, given site characteristics and management goals.

Technology Cost

Most of the cost data for vitrification technologies are estimates based on pilot-scale operations. Such data are suspect because they are based more on extrapolation than on experience. Such estimates are difficult to compare because the assumptions on which they are based may vary widely (D18248T, p. 55).

Many site-specific characteristics have an impact on vitrification technologies. One critical aspect of any thermal technology is the water content of the waste. Water dilutes feed material, requires energy to drive off, and physically limits the feed rate of waste. Feed preparation is another variable, which differs with the technology and with site-specific characteristics. Some technologies can accept complete barrels of waste at a time, while others require pretreatment and size reduction. Many estimates do not take into account site preparation and waste disposal costs. Only complete treatment life-cycle assessments can provide reliable comparison data, and such studies are, by definition, highly site and waste specific (D18248T, p. 55).

Various sources estimate vitrification costs as ranging from under \$100/ton to over \$1000/ton for units treating hazardous waste. These estimates are assumed to be for treatment only, not including pretreatment and disposal costs. The extreme variability of the costs may be attributable to differences in feed type and water content of the waste (D18248T, p. 55).

Plasma vitrification systems can heat the waste in one of two ways: either as a nontransferred arc or as a transferred arc. A nontransferred arc uses two internal electrodes. A small column of injected gas is heated by the electric arc, creating a plasma flow that extends beyond the tip of the torch. Nontransferred arcs heat by conduction and produce a dispersed heat that heats both the waste and the gas around the waste. Nontransferred arc melters can operate as in situ or ex situ processes (D11008N, pp. 3–7, 3–11).

A transferred arc uses the heated waste as reactor material. Electricity flows from a rear electrode through the wastes and out to a ground. Heating occurs in the wastes by convection, radiation, and electrical resistance. Transferred arcs require starter material or some other means to allow for materials to melt so the electric arc can be initiated (D11008N, p. 3–7).

Ex Situ Plasma Vitrification

Nontransferred Arc. Some ex situ nontransferred arc plasma vitrification systems that are summarized in the RIMS database are the Plasma Energy Applied Technology (PEAT, Inc.) thermal destruction and recovery (TDR) system (T0594), the Retech Incorporated plasma arc centrifugal treatment system (T0660), the MeltTran Ultimate Solution™ (T0505), Refranco Corporation sustained shock thermal plasma (T0648), and the ITEX plasma arc continuous-flow furnace (T0814). Cost estimate information is provided for the Retech vitrification technology and MeltTran vitrification technology. A cost estimate of the Retech Plasma Arc Centrifugal Treatment system is included below as a representative cost estimate for an ex situ, nontransferred arc vitrification system.

Cost estimates were prepared for the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration in June 1992 based on data from the vendor and data gathered during the evaluation. Costs were presented on a cost-per-ton basis. Estimates were given for different feed rates of the tested PACT-6 pilot-scale system, as well as for the PACT-8 full-scale system. Cost estimates were prepared for treatment rates of the PACT-6 of 500 lb/hr and 1000 lb/hr. The estimated treatment rate of the PACT-8 was 2200 lb/hr. For each treatment rate, estimates were included for online factors of 50 and 70%. For a feed rate of 500 lb/hr and an online factor of 70%, the cost is estimated at \$1816. For a feed rate of 2200 lb/hr, with the same 70% online factor, the cost is \$757 (D104585, p. 1). These costs are summarized in Table 1.

The estimate is based on the following assumptions:

- PACT unit installed at a fixed facility.
- Wastes treated equal to 2000 tons.
- Operating time of 24 hr/day, 5 days/week, 50 weeks/year.
- Improved feeder system, scrubber system, and a new power supply to the torch for the PACT-6 (D104585, pp. 17–20).

TABLE 1 Summary of the Estimated Costs in Dollars/Ton for Various Feed Rates and Online Operating Conditions for Plasma Arc Centrifugal Treatment (PACT) of Wastes

System	PACT-6 550 lb/hr		PACT-6 1000 lb/hr		PACT-8 2200 lb/hr	
Online factor	50%	70%	50%	70%	50%	70%
Site preparation	66	56	49	44	39	37
Equipment	252	180	141	101	140	100
Startup/fixed	559	405	323	239	331	250
Labor	1,280	914	640	458	291	208
Supplies	20	20	20	20	20	20
Consumables	188	183	123	120	112	110
Facility modification, repair, replacement	82	58	46	33	45	32
Total	2,447	1,816	1,342	1,015	978	757

Source: Adapted from D104585.

Among items not included in this estimate are:

- Permitting and regulatory costs
- Effluent treatment and disposal costs
- Analytical costs
- Site demobilization costs (D104585, pp. 18–23)

The costs of operating a PACT-2 system on site were estimated to be 30% greater than the costs of operating it at a fixed facility (if only the costs estimated in the SITE demonstration are considered). This is an approximate estimate, based on treating a total volume of 2000 tons of waste and a per diem of $60 per day per operator (D104585, p. 24).

Transferred Arc. Ex situ transferred arc plasma-heated melters that are discussed in the RIMS database include the Electro-Pyrolysis, Inc., direct current (DC) graphite arc furnace (T0240), the Science Applications International Corporation (SAIC) plasma hearth process (PHP) (T0696), the Oak Ridge National Laboratory glass material oxidation and dissolution system (T0569), and two processes developed by Molten Metal Technology: the catalytic extraction process (T0490) and the quantum-catalytic extraction process (T0535). Cost estimate information is provided for the Electro-Pyrolysis and the Molten Metal catalytic extraction process. Information from both estimates are included below as representative cost estimates for an ex situ, transferred arc vitrification systems. Cost information is also available on the SAIC PHP system.

Molten Metal Technology states that costs of the catalytic extraction process (CEP) are dependent on the feed type, feed properties, treatment rate, operating pressure, and location. In 1994, the vendor estimated that CEP processing would cost $100 to $250 per ton. The vendor claimed that the recovered materials could be sold, lowering treatment costs. Prices for recovered products can range for $80 per ton for some off-gases to $4000 per ton for condensed-phase products (D115479, p. 602; D12014P, p. 2166).

In 1994, Pacific Northwest Laboratories (PNL) estimated that a DC arc melter manufactured by Electro-Pyrolysis, Inc., capable of treating 1.5 to 2 tons per hour would have a startup cost of approximately $2 million (D116154, p. 4).

In a 1994 U.S. Department of Energy (DOE) study on system benefits associated with high-temperature melters, Brown et al. reported that high-temperature systems allowed for higher mass loading, a more dense final waste form, and required a lower characterization frequency than lower temperature Joule melters. In an estimate based on the treatment of DOE mixed

TABLE 2 Projected Remediation Costs for a Hazardous/Toxic Waste Contaminated Site Using In Situ Plasma Vitrification

Cost Category	Explanation	Cost (dollars)
Capital cost	10-year project life, 6-month project	0.5 million
Drilling cost	2 ft of overburden, 400 bore holes	0.5 million
Electricity cost	500 kW per ton of waste treated	0.6 million
Labor cost	5-person shift, 2 shifts per day	0.9 million
Maintenance cost	$100 per hour of operation	0.3 million
Total cost	Sum of above costs	2.8 million
Cost per ton of waste treated		130

Source: Adapted from D11871I.

wastes, it was estimated that treatment of the wastes using a Joule melter system would cost $4.9 to 6.3 billion. It was estimated that the use of a high-temperature melter system could save up to $2.6 billion over the life of the project (D115515, p. 652).

In Situ Plasma Vitrification In situ plasma-heated nontransferred arc vitrification systems discussed in the RIMS database include the Georgia Institute of Technology Construction Research Center's in situ plasma vitrification system (T0343) and the Teton Technologies, Inc., in situ waste destruction and vitrification system (T0786). A cost estimate is included in the Georgia Institute of Technology in situ plasma vitrification system.

In a 1994 evaluation of the Georgia Institute of Technology's in situ plasma vitrification, the cost of remediating a one-acre area contaminated to a depth of 10 ft using a 5-MW mobile plasma system was estimated at $130 per ton (D11871I, p. 716). A summary of the cost estimate is given in Table 2. According to researchers, treating radioactive wastes would cost from $250 to $400 per ton, and treating municipal waste contamination would cost approximately $50 per ton. Simple, non-waste-treatment soil stabilization operations would cost between $30 and $80 per ton (D15319F).

Information Sources

D104585, U.S. EPA, 1992

D115424, Steele and Mayberry, 1994

D115479, Chanenchuk et al., 1994

D115515, Brown et al., 1994

D11871I, Circeo et al., 1994

D12014P, Nagel et al., 1996

D15319F, Nemeth, web page, 1996

D18248T, Sigmon and Skorska, 1998

T0614

PolyIonix Separation Technologies, Inc.

Polymer Filtration

Abstract

The PolyIonix Separation Technologies, Inc., polymer filtration is a separation technology that removes metals from aqueous waste streams. Specialized, water-soluble polymers are added

to contaminated water, where they create a bond with the targeted metals. This bonded complex forms a larger compound that can be separated from the waste stream using ultrafiltration methods.

This technology is currently commercially available. PolyIonix Separation Technologies, Inc., offers polymer filtration for the treatment of metal-contaminated wastewaters from the electroplating and printed wire board industries.

According to the developer, polymer filtration has several advantages:

- Minimizes secondary wastes.
- Is an in-line treatment that continuously treats wastewater.
- Operates at low pressures and temperatures.
- Is more efficient than ion exchange resins.
- Is capable of releasing metal contaminants from surfaces.

Chelating polymers must be developed and evaluated according to the type of waste being treated. Because some contaminants may be present in relatively low concentrations with respect to other ions in waste solutions, polymers that have high binding and selectivity for the particular contaminant must be developed.

Technology Cost

The formulation of the polymer used in filtration varies with the waste stream type. Different polymers have different costs. The operating expenses associated with treating wastewater contaminated with nickel and zinc from the electroplating industry was estimated to be less than 1 cent per gallon (D21214W, p. 6).

Information Source

D21214W, Smith, 1998

T0615

Polymer-Based Stabilization/Solidification — General

Abstract

Polymer-based stabilization/solidification (S/S) is a technology for the ex situ treatment of radioactive, mixed, and hazardous wastes. It is a process in which polymers are created within the waste matrix to solidify and physically immobilize the hazardous constituents of contaminated materials. The goal is to prevent the migration of contaminants into the environment by forming a solid mass.

The goal of this technology is to trap and immobilize contaminants within the existing medium, rather than to remove them via chemical and/or physical treatments. Organic polymerization S/S has been used primarily to stabilize/solidify radioactive wastes. It has been applied on a limited basis to other wastes such as organic chlorides, phenols, paint sludges, cyanides, and arsenic. Polymerization can also be applied to heavy-metal-contaminated wastes, petroleum hydrocarbons, flue gas desulfurization sludge, electroplating sludges, nickel/cadmium battery wastes, ketone-contaminated sludge, and chlorine product wastes that have been dewatered and dried.

Technology Cost

The cost of treatment using polymeric stabilization/solidification may vary widely depending on the types of processes used, the materials involved, and the physical nature of the waste. Specific cost information may be found in the individual technology summaries.

T0616

Pozzolanic Solidification/Stabilization — General

Abstract

Stabilization/solidification (S/S) is a proven technology for the in situ or ex situ treatment of hazardous wastes and hazardous waste sites. It uses additives or processes to physically and/or chemically immobilize the hazardous constituents of contaminated soils, sludges, sediments, or even liquid wastes. The object of this technology is to prevent the migration of contaminants into the environment by forming a solid mass. Contaminants are trapped and immobilized within the existing medium, rather than removed via chemical or physical treatments.

Pozzolanic S/S systems use portland cement and pozzolan materials (e.g., fly ash) to produce a structurally stronger waste/concrete composite. The waste is contained in the concrete matrix by microencapsulation (physical entrapment). It is a chemical treatment that uses commercially available soluble silicate solutions and various cementious materials such as cement, lime, pozzolans, and fly ash. By addition of these reagents and rigorous mixing, the waste is fixed or stabilized. Contaminant mobility is reduced through the binding of contaminants within a solid matrix, which reduces permeability and the amount of surface area available for the release of toxic components.

Pozzolanic S/S has many varied applications in the field. It has been found to be a fast, simple, and low-cost measure for the treatment of a variety of wastes. It has been used for treating solids, liquids, sediments, and sludges from several industries, particularly those that produce heavy-metal-contaminated waste streams, and especially at sites where the soil contains lead.

Wastes that have been treated with pozzolanic S/S include oil sludges, auto shredder residue, lead and aluminum smelter slag, filter press cake, baghouse dust, incinerator ash, metal-contaminated soils, battery recycling waste, PCBs, plating sludges containing metals (aluminum, nickel, copper, lead, chromium, and arsenic), some organics, polychlorinated biphenyls (PCBs), waste acids, and creosote (D16635S, p. 3–1; D150232, pp. 1, 8). The pozzolanic S/S technologies are best suited for inorganics, including radionuclides.

Technology Cost

The costs associated with solidification/stabilization (S/S) technologies have generally been considered low compared with those for other treatment techniques. The reasons for this are the availability of rather cheap raw materials (e.g., fly ash, cements, lime) used in the more popular processes, simple processing requirements, and the use of readily available equipment from the concrete and related construction industries (D150141, p. 7.99).

The final costs are highly dependent upon site-specific conditions. Factors contributing to the final cost include the waste characteristics, such as its physical form and chemical makeup; the amount of pretreatment required; transportation of raw materials to the site and treated materials from the site; and other factors such as health and safety requirements and regulatory factors (D150141, p. 7.100).

Specific cost information may be found in the individual technology summaries.

Information Source

D150141, U.S. EPA, 1989

T0617

PPC Biofilter

Biofiltration Systems

Abstract

PPC Biofilter provides biofiltration systems that degrade volatile organic compounds (VOCs) from contaminated industrial exhaust. Biofiltration is typically used to reduce hazardous air

pollutants for regulatory compliance and odiferous compounds for odor control. According to vendor literature, this technology has been successfully implemented on commercial exhaust ranging from 100 cubic feet per minute (cfm) to 140,000 cfm and VOC concentrations below 1500 parts per million by volume (ppmv).

A low operating cost provides the main attraction to biofiltration technology. Biofiltration uses microorganisms to biologically oxidize chemical pollutants to water and carbon dioxide. The end result is the same as incineration with reduced energy costs. Biofiltration oxidizes the pollutants, so the technology does not experience the "regeneration" cost associated with carbon adsorption. It can also be superior to chemical scrubbing, which only provides a phase transfer from gas to water.

All information has been supplied by the vendor and has not been independently verified. Biofiltration systems are relatively large when compared to alternative control technologies. PPC Biofilter reports that the removal efficiencies vary for each application depending upon the chemical composition and mass loading.

Technology Cost

System designs vary from application to application. However, when biofiltration is economically competitive to alternate control technologies, the delivered and installed capital cost falls within the range of $12 to $40/cfm design flow. This estimate is for a turnkey system that includes engineering, fabrication, installation, and startup (personal communication: S. Standefer, PPC Biofilter, 10/97).

At a chemical processing facility, a methanol tank emits approximately 4000 ft^3 of air saturated with methane on a daily basis. The entire emission is concentrated over a time period of 2 to 3 hr. The off-gas passes through a scrubber that removes at least 95% of the methanol. The liquid effluent from the scrubber is processed by an air stripper that removes the methanol. The gaseous effluent from the air stripper enters the biofilter with a more constant methanol loading than the off-gas from the methanol tank. According to the vendor, the capital costs for this system was $98,000. The vendor estimated that the system's operating costs would be approximately $0.25/hr. This estimate includes electrical cost to run all pumps and the blower to pull the air through the system (D213194).

According to the vendor, the capital and operating costs associated with a PCC biofiltration system vary depending on site-specific factors. The capital cost of the system is directly related to the size of the reactor. The size of the reactor is dependent on the flow rate, chemical composition, and concentration. The operating costs often include electricity consumption, natural gas consumption, steam, maintenance cost, filter media replacement, water consumption, and media disposal. These operating costs are directly related to the design and size of the biofilter (D213161, pp. 1 & 2).

An economic comparison of biofiltration and thermal oxidation was provided by a recent trade publication authored by a PPC chemical engineer (D16218F). The analysis for Case 1 was based on a 4000-cfm airstream containing organic contaminants typically found in the flexographic printing industry. Biofiltration was compared to catalytic oxidation. Lower operating costs favored biofiltration by almost 40% after 5 years of operation.

In a similar comparison with a flow rate of 6000 cfm for Case 2, the biofilter's long-term operating costs lowered the 5-year cost by almost 35%. Table 1 shows these comparisons (D213172, pp. 2, 3; D16218F).

Information Sources

D16218F, Standefer, 1996

D213161, Standefer and Willingham, undated

D213172, PPC Biofilter, undated

D213194, PCC Biofilter, undated

TABLE 1 Comparison of the 5-Year Costs Associated with the PCC Biofilter and Catalytic Oxidizers

	Case 1		Case 2	
	Biofilter	Catalytic Oxidizer	Biofilter	Catalytic Oxidizer
Installed capital costs	\$246,000	\$300,000	\$342,000	\$350,000
Annual utility costs	\$3,000	\$29,000	\$4,300	\$43,400
Media or catalyst replacement costs over 5 years	\$31,250	\$21,400	\$50,000	\$61,200
Total cost over 5 years	\$292,250	\$466,400	\$413,500	\$628,200

Source: From D213172.

T0618

Praxair, Inc.

Mixflo

Abstract

The Praxair Mixflo™ oxygenation system is a proprietary, commercially available technology used for the treatment of aerobically biodegradable contaminants. Mixflo can be used in situ to treat lagoon wastewater or ex situ to treat soil and sludge. The technology injects and dissolves pure oxygen into slurries, increasing contaminant biodegradation rates. Unlike aeration, nitrogen is absent during the Mixflo process. As a result, less air stripping occurs and fewer volatile organic compounds (VOCs) are released to the air from the reaction mixture.

According to the vendor, Mixflo has the following advantages in wastewater treatment applications:

- Reduces VOC emissions by more than 99% compared to conventional treatment using aeration.
- Experiences minimal down time.
- Reduces evaporative cooling and foaming.
- Can increase treatment capacity of existing treatment plants.
- Minimizes production of extra sludge.
- Prevents the formation of aerosols and odors.
- Produces less noise than turbines or air blowers.
- Reduces power consumption.
- Minimizes the area required to build or expand treatment plants.

Mixflo can only be used to treat aerobically biodegradable contaminants; it cannot treat metals. In addition, the technology only treats slurries that can be pumped and can pass through a 0.5-inch mesh.

Technology Cost

The vendor claims that Mixflo is an economical option for capacity expansion and emission control at wastewater treatment plants. According to the vendor, upgrading air-based activated sludge treatment systems with Mixflo can reduce energy costs by greater than one third (D22912J, p. 12).

TABLE 1 Construction and Operating Cost Comparison for Mixflo Oxygenation System versus Fine Bubble Diffuser Aeration

Cost Category	Fine Bubble Diffuser Aeration ($)	Mixflo Oxygenation System ($)
Aeration equipment	1,121,990	1,018,000
Field construction	677,500	740,750
Operations labor	3,686,400	3,225,600
Management	1,620,000	1,417,500
Oxygen	—	1,296,000
Air monitoring (lab)	2,280,000	1,428,000
Power	2,160,000	1,451,520
Spare parts	269,278	160,335
Maintenance	1,346,388	641,340
Supplies	480,000	420,000
Total cost difference comparison[a]	13,641,556	11,799,045

Source: Adapted from D14085C.
[a]The above costs exclude all cost items that are common to both aeration systems. Cost items such as construction management, the chemical addition system, and installation of air monitoring systems were excluded.

The vendor notes that oxygen-based dissolution technologies like Mixflo have traditionally been more expensive than air-based systems. The higher costs for oxygen-based dissolution systems were due to low oxygen utilization and the higher energy requirements for mixing. According to the vendor, Mixflo has become more cost competitive with the recent development of cheaper oxygen-producing technologies such as vacuum pressure swing adsorption (VPSA). The VPSA technology can produce oxygen for as little as $40 per ton (D22915M, p. 5).

The total cost to remediate approximately 300,000 tons of tarlike sludge and subsoil from a lagoon at the French, Ltd., Superfund Site in Crosby, Texas, was $49,000,000. Costs directly related to treatment activities (which included the use of a Mixflo system) were $26,900,000. This value corresponds to $90 per ton of soil and sludge treated. According to the design contractor, costs for a second-generation system that does not require pilot studies or sheet pile work would be about 40% less than those incurred at French, Ltd. (D13194C, pp. 14, 16).

A construction and operating cost comparison between Mixflo technology and fine bubble diffuser aeration is presented in Table 1.

Information Sources

D14085C, ENSR Consulting and Engineering, 1990

D13194C, U.S. EPA, 1995

D22912J, Wrampe and Lala, undated

D22915M, Storms, 1997

T0619

Praxair, Inc.

Praxair Oxygen Combustion System

Abstract

The Praxair Oxygen Combustion System (OCS) is an oxygen burner that produces a flame with a temperature comparable to the flame temperature of conventional air burners. The technology can increase incinerator throughputs, while decreasing fuel requirements and emissions. An OCS was used to enhance the performance of the U.S. Environmental Protection Agency's (EPA's) Mobile Incineration System (MIS). This OCS unit assisted with the treatment of over 7 million pounds of dioxin-contaminated material, including soil, lagoon sludge, plastics, trash, grass, protective clothing, and wood. OCS is commercial availability through Praxair. Praxair has also developed a similar treatment technology, known as Oxygen-Enhanced Sludge Incineration.

According to Praxair, the OCS has the following advantages:

- A relatively low-flame temperature that is adjustable
- Effective gas circulation
- Feedback controls that quickly adjust to changes in feed media

The flame characteristics of the burner could contribute to slagging problems.

Technology Cost

The principal economic benefit from oxygen combustion (over air combustion) is derived from increases in media throughput. By increasing throughput, the large fixed portion of daily incinerator operating costs is spread over a much larger quantity of waste processed. For example, a doubled throughput for mobile/transportable incinerators can reduce the allocated incineration cost of contaminated soil by about $100 to $500 (1990 dollars) per ton of waste. In this scenario, the cost of oxygen is typically between $10 to $50 (1990 dollars) per ton of waste incinerated (D142256, p. 505).

In the summer of 1987, the Oxygen Combustion System (OCS) was used to enhance the performance of the U.S. EPA's Mobile Incineration System. The OCS, along with other system modifications, helped double the feed rate of the MIS. According to the EPA, material processing costs were reduced from $2800 per ton before OCS installation to $1100 per ton after installation (D11931D, p. 3).

A similar technology called Oxygen-Enhanced Sludge Incineration was involved in a 5-month study conducted by Praxair and the New York State Energy Research and Development Authority (NYSERDA). This study was carried out at Monroe County's Frank E. Van Lare Sewage Treatment Plant in Rochester, New York. One of the facility's two 11-hearth furnaces was converted for use with oxygen for the test. The total cost of this study was $400,000 (D22917O, p. 1).

Information Sources

D11931D, U.S. EPA, 1990
D142256, U.S. EPA, 1990
D22917O, Hodson, 1996

T0620

Praxis Environmental Technologies, Inc.

In Situ Thermal Extraction

Abstract

In situ thermal extraction is a process for the removal of volatile and semivolatile organic compounds (VOCs and SVOCs) from contaminated soils and groundwater. The process primarily treats chlorinated solvents such as trichloroethylene (TCE), tetrachloroethylene (PCE), and dichlorobenzene; hydrocarbons such as gasoline, diesel, and jet fuel; and mixtures of these compounds.

The process can be applied to the cleanup of source areas such as dense pools of non-aqueous-phase liquid (NAPL) below the water table surface, light NAPL pools floating on the water table surface, and NAPL contamination remaining after conventional pumping techniques. Subsurface conditions after application of the thermal process are generally amenable to biodegradation of residual contaminants.

The process is applicable in less permeable soils by the use of novel delivery systems such as horizontal wells or fracturing.

The technology requires the site to have a barrier layer below the depth of contamination. Dependent upon the type of contamination, this layer can be either a high-permeability layer, a low-permeability layer, or the water table. Low-permeability soils can isolate the contaminants from contact with the steam, and thus impede contaminant recovery.

Technology Cost

During the field demonstration in 1997 at the Department of Defense's (DOD's) Operable Unit 2, Hill Air Force Base in Utah, approximately 908 gal of dense, non-aqueous-phase liquids (DNAPLs) were removed from contaminated soils. The cost of the demonstration was \$230/yd^3 of soil treated and \$165/gal of DNAPL removed. These costs included the purchase of all the equipment and an extensive monitoring network. It is estimated that future applications at the site would require roughly half as many wells and the boiler rental would be restricted to a much shorter period. These conditions would lower the direct treatment costs to \$103/yd^3 of treated soil and \$74/gal DNAPL removed (D18518W, p. 216).

According to vendor-supplied information, the estimated price range for in situ thermal extraction is \$50 to \$125/yd^3 of soil. This does not necessarily include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals. Depth of contamination and moisture content of the soil have a significant impact on the cost of remediation (D103924, p. 16).

Information Sources

D103924, VISITT, July 1995

D18518W, Stewart, et al., 1998

T0621

Pressure Dewatering — General

Abstract

Pressure dewatering is an extension of bioventing technology. In bioventing, air is injected into the soil to promote the aerobic biodegradation of contaminants, such as hydrocarbons. Pressure dewatering involves adding this air at a sufficient rate to cause an increase in the groundwater pressure that results in groundwater flow away from the air injection site. Subsequent to the pressure dewatering, gravity drainage occurs and the combined effect increases the radius of influence and zone of remediation, and also opens the "smear zone" to airflow and therefore increased biodegradation.

Bioventing is one of the most widely applied means of remediating vadose zone soils. The process has been full scale for a number of years and is available from a number of vendors. Pressure dewatering is an aspect of bioventing rather than an independent technology.

Because water is generally considered incompressible, applying pressure to the water table surface depresses the water proportionally to the water pressure. This pressure causes a radial depression of the water table about the pressure injection point. The depression dewaters a section of the smear zone and saturated zone proportionally to the pressure applied at the injection point. Dewatering of the smear zone increases the volume of the smear zone and

saturated zone proportionally to the pressure applied at the injection point and consequently it increases the volume that can be biodegraded through bioventing. Removing hydrocarbons from the smear zone improves groundwater quality by source removal.

Technology Cost
No information available.

T0622

Pressure Systems, Inc.

Phoenix Ash Technology

Abstract
The Phoenix Ash Technology (PAT) is an ex situ stabilization and solidification technology that encapsulates hazardous, mixed, and radioactive wastes. The wastes are combined with pozzolanic (cement-like) fly ash produced in coal-fired generating plants. The PAT process uses a hydraulic ram to apply pressure to the materials for a few seconds, remove void spaces, and form uniform blocks. The process occurs at ambient temperatures. Pozzolanic reactions between the fine silicate or alumina material and the wastes result in a slowly hardening material. According to the Environmental Protection Agency (EPA) in 1996, the PAT process was commercially available through Pressure Systems, Inc., of Albuquerque, New Mexico (D20799S). However, RIMS has been unable to contact the vendor.

According to the EPA, some advantage of the PAT process are that it:

- Is a simple to operate, low-cost treatment.
- Reduces the volume of contaminated material.
- Provides rapid cure times.
- Allows for high waste loading.
- Produces a product that is high in strength and low in leachability.

The PAT process has been unable to stabilize organic materials such as rubber crumbs or wood chips because these substances have a memory effect and rebound to their original size after compression. The process requires low moisture content in the waste stream because waste loading is sensitive to moisture content. For hazardous and mixed wastes, influent particle size must be less than 0.25 inches in order to achieve proper brick formation and adequate stabilization.

Technology Cost
The costs associated with the PAT process will vary based on site-specific conditions and the costs of pozzolan additives, operating safety requirements, and labor. The estimated costs associated with the stabilization of fine-grained soils that do not require pretreatment and do not pose extreme handling hazards are between \$30 and \$50 per ton. For the stabilization of coarse-grained soils, costs were estimated between \$40 and \$60 per ton. Pretreatment, containment, and high-efficiency particulate air (HEPA) filtration would add to these cost estimates (D20799S, pp. 23, 24, 66).

Information Source

D20799S, U.S. EPA, 1996

T0623

Princeton University

Magnetic Extraction of Nonionic Organic Pollutants

Abstract
Princeton University is researching magnetic extraction of nonionic organic pollutants. The technology is based on the use of anionic surfactant-coated magnetic particles to absorb and remove targeted contaminants from a soil slurry. The coated particles are then recovered by magnetic separation. The technology has been evaluated in a bench-scale treatability study; researchers are searching for a suitable site to carry out a pilot-scale demonstration.

Researchers are interested in this technology because it removes low-solubility organic compounds that are not readily amenable to bioremediation or current pump-and-treat practices. These compounds typically are sorbed onto the naturally occurring organic materials in the soil. This technology has the potential to treat low-solubility organic compounds with minimal generation of secondary waste.

The effectiveness of the surfactant is dependent on the physical and chemical properties of the soil, and on pH. Process pH is most effective in the range between 3.0 and 8.0.

Technology Cost
No available information.

T0624

Proactive Applied Solutions Corporation

LEADX

Abstract
LEADX™ is a chemical additive that was developed to treat material contaminated with lead or other heavy metals in situ. LEADX may be added directly to soil or incorporated into sandblasting materials or paint thinners. LEADX penetrates the contaminated material and chemically bonds with heavy-metal contaminant to form an insoluble, nonleachable compound. The vendor claims that once bonded, the lead cannot be absorbed by plants or animals and is chemically rendered immobile. According to the vendor, it has been used in the following applications for the treatment of lead:

- Recycling of computer monitor or television cathode ray tubes (CRT) or other lead-contaminated glass
- In situ soil remediation
- Lead paint removal and remediation
- Recycling of lead-contaminated sludge

LEADX was developed and is manufactured by Proactive Environmental Research and Development, Inc. (PERDI). PERDI indicates that patents are pending in the United States for processing and treatment of CRT such as those used for displays in televisions and computer monitors. Patents are also pending in the United States for the use of LEADX as an abrasive additive for sandblasting to immobilize lead from lead paint residue. LEADX is distributed by Proactive Applied Solutions Corporation (PASCO). EnviroBest Corporation markets two paint removers containing LEADX called PR-40/LEADX™ and PR-40AF/LEADX™.

During a bench-scale, sandblasting demonstration, the LEADX abrasive additive was unable to reduce airborne concentrations of lead.

Technology Costs

The lead paint remover PR-40 with LEADX is available through the EnviroBest Corporation. A 5-gal pail of PR-40 with LEADX costs $210.00. A 55-gal drum of PR-40 with LEADX costs $2365.00 (D20236Y, p. 13).

Information Source

D20236Y, EnviroBest Corporation, undated

T0625

Process Technologies, Inc.

Photolytic Destruction Technology

Abstract

The Process Technologies, Inc. (PTI), photolytic destruction technology (PDT) photochemically oxidizes gaseous organic compounds within a reaction chamber. PDT uses low-pressure ultraviolet (UV) lamps to emit high-energy photons that break down the molecular bonds of target chemicals and create free radicals from volatile organic compounds (VOCs). The resulting by-products chemically react with a solid reagent to form nonhazardous salts. This technology is capable of destroying mixtures of chlorinated and nonchlorinated VOCs.

The vendor states that the technology has been installed at private industrial sites and military installations for the destruction of VOC off-gases from soil vapor extraction (SVE) systems, air strippers, and process tank vents. The technology is patented and commercially available. The results from demonstrations at three military installations are included in case study overview.

The vendor states the following advantages of PDT technology:

- Destroys chlorinated VOCs at high concentrations of up to 50,000 parts per million by volume (ppmv).
- Allows for easy installation; systems are skid or trailer mounted.
- Capable of achieving 90% online availability.
- Does not require large exhaust stacks and may consequently avoid negative public sentiment.

The system is presently limited to the treatment of vapor-phase waste streams. The process is not suitable for the disposal of solids, sludges, or liquids that cannot be readily vaporized. Tests have shown that the present design is not capable of destroying perfluorocarbon (PFC) compounds as efficiently as it destroys halogenated solvents.

Technology Cost

The estimated cost for PDT is $4 to $6 (all costs in 1995 dollars) per pound of VOC treated and $3 to $5 per pound of chlorofluorocarbons (CFCs) treated. This estimate may not include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals.

Factors that have a significant effect on unit price include the following:

- Quantity of waste
- Target contaminants

- Initial contaminant concentration
- Target (i.e., final) contaminant concentration (D103913, p. 29)

In 1998, the Naval Environmental Leadership Program (NELP) conducted a demonstration of PDT technology at the Naval Air Station (NAS) North Island Site 9 near San Diego, California. The total demonstration cost was $93,726 (all costs in 1998 dollars), including work plan, mobilization/demobilization, site work, liquids collection and containment, treatment, monitoring, sampling and analysis, and residuals disposal. The most expensive component of the demonstration cost of $57,762.50 consisted of the monitoring, sampling, testing, and analysis of the SVE gas stream, process outlet, and process residues (D18514S, p. 190). The data from the demonstration were used to estimate the cost of implementing a 3000-standard-cubic-feet-per-minute (scfm) PTI system at NAS North Island Site 9. The estimated unit cost for such a system was $3.77/lb of VOC treated. According to PTI, the commercialization of the technology over the next few years will lower the treatment costs further (D18514S, p. 191). Please refer to Table 3–15, p. 190 of D18514S, for more information regarding the cost breakdown for the demonstration.

Information Sources

D103913, VISITT Version 4.0, 1995
D18514S, Federal Remediation Technologies Roundtable, 1998

T0626

Product Services Company

Oil Gator

Abstract
Oil Gator is a chemically modified cellulosic fiber that promotes in situ biodegradation of hydrocarbons. According to the manufacturer, when the fiber is moistened, the bacteria reproduce and adapt to the available hydrocarbon food source. Oil Gator also extracts hydrocarbons by adsorption.

Oil Gator was invented by Ted Dickerson of Product Services Company of Jackson, Mississippi, who currently manufactures the product. The technology is patented. Vendors of Oil Gator include Product Recovery Management of Durham, North Carolina; Environmental Remediation Technology (Enertech) of Vancouver, British Columbia, Canada; Pacific Environmental Products of Eugene, Oregon; Gator International of Penticton, British Columbia; and Haz-Con Environmental, Inc., of Lockport, Illinois.

According to the vendor, Oil Gator offers the following advantages:

- Encapsulates hydrocarbons, reducing the chance of contaminant ignition.
- Eliminates bioavailability of hydrocarbon contaminants.
- Allows for in situ or ex situ applications.
- Biodegrades once targeted contaminants are eliminated.

According to Product Services Company, treatment will be most efficient at temperatures between 40 and 120°F. Pesticides, degreasing agents, and heavy metals may have an adverse impact on the microbial action. The pH should be between 4.5 and 9.5, with an optimum of 7.0. Moisture content should be maintained at 30% throughout the remediation.

Technology Cost

According to Product Services Company, 1022 tons of contaminated soil were treated by use of 130 thirty-pound bags of Oil Gator. The material costs of the treatment were estimated to be $2 per ton of soil. The manufacturer estimated that the overall treatment costs would be $27 per ton (D16094L, p. 12).

At another Oregon site, it was estimated that remediation costs were $16 per ton of soil treated (D16094L, p. 12). No additional information is available.

A Canadian supplier of Oil Gator products listed the cost of a 1.5-ft^3 bag of Oil Gator at $55 (Canadian dollars) and the cost of an 8-liter bucket of Oil Gator at $25.00 (Canadian dollars) (D22685R, pp. 1–2).

Information Sources

D16094L, vendor literature

D22685R, Gator International, undated web page

T0627

Pseudomonas sp. Strain KC — General

Abstract

Pseudomonas sp. strain KC is a bacterium capable of degrading carbon tetrachloride (CCl_4), under aerobic or anaerobic conditions, without producing chloroform ($CHCl_3$), a compound that is persistent and harmful to human health. Proof-of-concept and bench-scale research has supported further field-scale evaluation of *Pseudomonas sp.* strain KC as a method of in situ bioremediation of CCl_4. Under moderately alkaline conditions, with low dissolved concentrations of iron and copper, strain KC secretes factors that rapidly degrade CCl_4. While certain indigenous microorganisms are able to transform CCl_4, they produce chloroform, which requires special in situ by-product controls.

This technology is not yet commercially available. Much of the research has been done at the Center for Microbial Ecology at Michigan State University, which is pursuing patents for the technology and its related processes. Golder Associates, Inc., are an anticipated vendor when the technology becomes available.

Researchers claim advantages of *Pseudomonas* sp. strain KC include the following:

- Transforms CCl_4 into benign products such as carbon dioxide, without producing chloroform.
- Grows well in subsurface environments.
- Potentially cost-effective method for remediating CCl_4 in groundwater.

Limitations of using *Pseudomonas* sp. strain KC include the following:

- Species requires a moderately alkaline environment.
- Subsurface matrix must be permeable and allow colonization of KC.
- Production of chloroform depends on iron concentrations: higher levels of iron resulted in a greater production of chloroform.

Technology Cost

No cost information is available as the technology is not yet commercially available. When and if it becomes commercially available, Golder Associates is an anticipated vendor.

T0628

PTC Enterprises

BioTreat System

Abstract
The BioTreat™ system is an in or ex situ treatment that uses specifically selected enzymes and nutrients to encourage biodegradation of hydrocarbons with the indigenous microorganisms. According to the vendor, the system has been used at a number of sites, however, no further information was available. The current availability of this technology is uncertain, however, the vendor has indicated that they plan to offer an improved version of BioTreat in the future.

All information was provided by the vendor and was not independently verified.

Technology Costs
No available information.

T0629

Pulse Sciences, Inc.

X-Ray Treatment

Abstract
X-ray treatment is being investigated for the decontamination of organic contaminants in soils or aqueous solutions. Bench-scale ex situ experiments have been conducted, and in situ treatment has been suggested as possible. The technology is not currently commercially available.

X-ray treatment is based on in-depth deposition of ionizing radiation. X-rays, or energetic photons, collide with matter to generate a shower of lower energy secondary electrons within the contaminated waste material. These secondary electrons then react to form highly reactive radicals, which in turn react with contaminants to form compounds such as carbon dioxide, water, and oxygen. Using this technology, wastes can be treated in containers, as the X-rays will pass through the walls of standard 55-gal drums, thus minimizing handling requirements.

This treatment is for organics only and in situapplication is, at this point, purely hypothetical. The maximum energy of the X-rays is generally limited to less than 10 MeV to avoid nuclear activation of the working media. Also, carbonate and bicarbonate compounds found in some aqueous solutions significantly increase the X-ray dose and treatment time required to treat the material.

Technology Costs
No cost information is available, however, Pulse Sciences estimates that the cost of high-throughput X-ray processing will be competitive with alternative processes (D10848F, p. 403).

Information Source

D10848F, SITE Technology Profile, 1995

T0630

RLC Technologies, Inc.

Portable Anaerobic Thermal Desorption Unit (ATDU)

Abstract
The Anaerobic Thermal Desorption Unit (ATDU), also known as the Indirect Heated Unit, is an ex situ technology suitable for treating contaminated soil, sludges, and sediments. It desorbs

TABLE 1 Cost of Treated Contaminated Soils Using the ATDU

Client	Location	Amount Treated (tons)	Cost per ton (in $)
Confidential	Carteret, New Jersey	2,000	78
Air National Guard	Martinsburg, West Virginia	3,480	108
Norfolk Southern Railroad	Alexandria, Virginia	36,000	33.50
CSX Railroad	Martinsburg, West Virginia	6,004	39.40
U.S. Navy	Norfolk, Virginia	25,000	42.68

Source: Adapted from D14881W and D150414.

volatile and semivolatile contaminants in an oxygen-deficient atmosphere, thus eliminating oxidation and the formation of more hazardous compounds. The ATDU removes polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), trichloroethylene (TCE), perchloroethylene (PCE), coal tars, creosotes, pesticides, solvents, and petroleum hydrocarbons.

According to the vendor, ATDU technology has been employed at numerous sites throughout the United States for soil remediation and is commercially available.

The vendor lists the following advantages of the ATDU system:

- Produces low emissions.
- Allows treatment without large discharge ports or stacks.
- Operates in an oxygen-deficient environment, minimizing the generation of hazardous compounds during treatment.
- Allows for potential recovery of contaminants.

Most metals cannot be treated by ATDU technology. Soils may require pretreatment if they contain oversized materials or greater than 30% moisture. The off-gas stream may require additional treatment by activated carbon filtration or thermal oxidization to remove light hydrocarbons.

Technology Costs

The vendor estimates the price of remediation, using the ATDU, at $60 to $300 per ton. Factors influencing cost include initial and target contaminant concentrations, quantity of waste, moisture content of soil, and labor rates. According to the vendor, cost can be offset through recycling of the "waste" after its separation from the solid matrix. In addition, the vendor claims that anaerobic remediation costs 40 to 70% less than incinerating or landfilling contaminated soil (D150414, pp. 2, 36).

The vendor states that ATDU technology has been used at several sites in the United States. Table 1 outlines the remediation costs from selected sites.

Information Sources

D14881W, Purgo, undated

D150414, VISITT 5.0, 1996

T0631

Purus, Inc.

Pulsed UV Irradiation

Abstract

Pulsed ultraviolet (UV) irradiation is an ex situ technology for the treatment of soils and groundwater contaminated with volatile organic compounds (VOCs). The system uses a xenon

pulsed-plasma flashlamp that emits short wavelength UV light at very high intensities. The process carries the contaminants into the vapor phase, where UV irradiation converts VOCs into less hazardous compounds.

Conventional UV treatment systems use mercury lamps to initiate indirect photolysis: UV light is used in conjunction with an oxidant or catalyst to form hydroxyl radicals that initiate reactions that destroy contaminants. On the other hand, pulsed UV irradiation uses xenon pulsed-plasma flashlamps to initiate direct photolysis: organic contaminants absorb sufficient UV light energy to break their molecular bonds. The mercury lamp has most of its output at wavelengths above 250 nm, whereas the xenon flashlamp has a maximum output at 230 nm and below—a shift that represents a 1 to 2 order of magnitude increase in UV light absorptivity of many VOCs, thereby greatly increasing the rates of direct photolysis.

Purus, Inc., is no longer in business. It is not known if this technology is currently commercially available.

Benzene and some halogenated compounds including carbon tetrachloride, trichlorotrifluoroethane (Freon 113), and dichloroethane absorb light weakly and thus photolyze relatively slowly. Therefore even shorter wavelengths than those available from the current technology are needed to create a commercially viable, direct photolysis process for these compounds.

Pulsed UV irradiation has been used in field demonstrations at the Lawrence Livermore National Superfund Site 300, 15 miles east of Livermore, California, and at the Savannah River Superfund Site near Aiken, South Carolina.

Technology Cost

Consumables, such as lamps, were estimated at $250 per lamp, with a life expectancy of 1000 hr at full power (30 Hz). Total operating costs of the system were estimated to be $0.85/hr in 1994. The cost of equipment used in a U.S. Department of Energy study was approximately $150,000 (D13776S, p. 33).

Based on 1998 literature, the total treatment cost for UV oxidation is approximately $13,726,000 for a 3-year remediation project. This corresponds to $19.61 per 1000 gal of groundwater treated, or $1830/lb of organic contaminants removed. Treatment costs included system, mechanical, structural, electrical, civil, one-year operation and maintenance (O & M), and system startup costs. The annual cost of O & M averaged $763,000. The costs are estimated based on a 3-year treatment of 7500 lb of organic compounds removed from 700 million gallons of extracted groundwater at the Bofors Nobel Superfund Site, Muskegon, Michigan. Cost data are based on the available records from the facility (D18881C, 1998).

Information Sources

D13776S, Schneider et al., October 1994

D18881C, Federal Remediation Technologies Roundtable, 1998

T0632

Pyrolysis—General

Abstract

Pyrolysis is defined as the chemical decomposition or change brought about by heating in the absence of oxygen. When hazardous wastes containing carbon undergo pyrolysis, gaseous components and a solid residue containing fixed carbon and ash is formed. In a pure pyrolysis mode, wastes are heated in an indirect fashion in the absence of air or flue gases. In practice, it is not possible to achieve a completely oxygen-free atmosphere, so modified forms of pyrolysis are used that rely on oxygen-deficient (also called starved-air) heating methods.

The RIMS library/database contains many technologies that can be operated in a pyrolysis mode. They include both in situ and ex situ methods, vitrification techniques, as well as technologies used for gasification. A list of these technologies can be found by searching under the technology category "pyrolysis."

The following are listed as advantages of pyrolysis technologies:

- Low-temperature pyrolysis technologies have shown increased refractory life and reduced maintenance requirements.
- Entrainment of particulate materials is reduced, which lessens the need for particulate emission control equipment.
- Endothermic nature of the process renders it easier to control.
- Heterogeneous solid or liquid waste can be homogenized into a high-heating value gaseous stream by pyrolysis.
- Recoverable constituents are concentrated in the solid residue or char.
- Volume of waste is significantly reduced.
- Condensible vapors with economic value can be recovered.
- Noncondensible combustible vapors can be used as a source of energy.

The effectiveness of this technology may be limited by the need to destroy products of incomplete combustion (PICs), principal organic hazardous constituents (POHCs), or carcinogens present in the waste. There may be specific feed size and material handling requirements that impact the applicability and cost at specific sites. Drying may be required prior to treatment. Highly abrasive feed may damage some processor units. The treated material may require stabilization prior to disposal. In addition, some of the energy content in the waste feed may be retained in the solid char.

Technology Costs

There are many pyrolysis technologies included in the RIMS library/database. Cost estimates are provided for the following technologies: Electro-Pyrolysis, Inc., DC Graphite Arc Furnace (T0240); Eli Eco Logic International, Inc., Gas-Phase Chemical Reduction (T0242); EnerTech Environmental, Inc. SlurryCarb Process (T0254); Georgia Institute of Technology, In Situ Plasma Vitrification (T0343), Geosafe Corporation In Situ Vitrification (T0344); Hydrocarbon Technologies, Inc., Recovered Oil Pyrolysis and Extraction (ROPE) (T0387); Plasma Energy Applied Technology, Thermal Destruction and Recovery (T0594); Pyrovac International, Pyrovac Process (T0633); Scientific Ecology Group (SEG), Steam-Reforming-Synthetica Technologies Detoxifier (STD) (T0698); TerraTherm Environmental Services, Inc., Thermal Blanket for In Situ Thermal Desorption (T0784); TerraTherm Environmental Services, Inc., Thermal Wells (T0785); Texaco, Inc., Texaco Gasification Process (T0787); University of Missouri, ChemChar Process (T0531); Vance IDS, Inc., Vance Incandescent Disposal System (IDS) (T0854); Western Product Recovery Group, Inc., Coordinate Chemical Bonding and Adsorption (CCBA) Process (T0880).

According to information published by the U.S. Environmental Protection Agency (EPA) in 1994, costs will vary according to the technology chosen and site conditions. As a general rule, costs go up with increased moisture content. Limitations in the particle size of contaminants and other material handling requirements will also impact applicability and costs at specific sites (D10895M, p. 4–106).

Information Source

D10895M, EPA, 1994

T0633

Pyrovac International, Inc.

Pyrocycling Process

Abstract
The Pyrocycling™ process is a vacuum pyrolysis-based technology. The process involves thermally decomposing waste feedstock into pyrolytic oils suitable for petroleum reprocessing or other uses. According to the vendor, pyrolysis under vacuum reduces the amount of secondary degradation products that would occur during atmospheric pressure pyrolysis. As a result, pyrolytic products are of high quality and can be reintroduced into the economy.

The Pyrocycling™ process is a commercially available technology. The marketing of the product is done by Pyrovac International, Inc. while process implementation information is offered through the Pyrovac Institute, Inc., where research and development activities are conducted.

The process is used on petroleum sludges, used tires, biomedical waste, automobile shredder residues, bark residues and municipal solid wastes. It is limited to treating organic wastes and contaminated soil. For soil contaminated by polychlorinated biphenyls (PCBs), vacuum pyrolysis cannot destroy the PCBs but will concentrate them in the pyrolytic oils. The process cannot be used to treat mine tailings.

Studies have shown that the Pyrocycling process is economically competitive with other technologies. In addition, by-products resulting from the process can often be sold.

The vendor claims the following advantages for the technology:

TABLE 1 Summary of Treatment Cost for a 5-ton/hr Unit in Canadian Dollars

Variable Costs	
Mobilization and transportation	$100,000
Supervision	65,000
Manpower	365,000
Maintenance	54,000
Treatment of the aqueous effluent[a]	
Laboratory analysis	35,000
Methane fuel	250,000
Cooling water	7,000
Total	876,000
Fixed Costs	
Depreciation	86,000
Taxes and insurances	22,000
Overheads	86,000
Safety, storage	35,000
Financial costs	150,000
Administration expenses	100,000
Total	479,000
Variable cost plus fixed costs	1,355,000
Cost per ton of soil treated	37.00

Source: D14695W, Roy et al., 1994.
[a]Not included in the costs.

- Wastes are mainly recovered in the form of oils, solid residues, water, and a small quantity of gas:
- Performance exceeds current Quebec environmental standards:
- Products and by-products can be sold:
- There is no need for a complex gas scrubbing system.

Technology Costs
An economic evaluation was performed in 1994, by analyzing the capital and operational costs for a 5-ton/hr prototype transportable treatment unit. The selected unit runs 24 hr a day, 305 days a year, and will treat 36,600 tons of hydrocarbon-contaminated soil a year. The total investment cost, including equipment, engineering and supervision, construction, and contingencies was estimated to be 950,000 in Canadian dollars for the 5-ton/hr unit. The estimated treatment costs are outlined in Table 1. Operating costs were calculated to be $37 per ton, not including the cost of treating the aqueous and oil phases (D14695W, pp. 127–128).

Information Source

D14695W, Roy et al., 1994

T0634

QED Environmental Systems

Stackable Tray Air Strippers

Abstract
E-Z Stacker and E-Z Tray are commercially available modular air strippers for the ex situ removal of volatile organic compounds (VOCs) from groundwater. E-Z Stacker consists of 4 or 6 stacking units; E-Z Tray units are arranged in pull-out drawers. The multiple sieve tray design of the E-Z Stacker uses forced-draft air bubble generation to provide VOC removal. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0635

QED Environmental Systems, Inc.

Ferret In-Well Separator

Abstract
The QED Environmental Systems Ferret™ in-well separator removes hydrocarbons from groundwater. QED Environmental Systems, Inc., has regional distributors of its Ferret in-well separator from whom the product is commercially available.

The Ferret process actively draws in water, as well as free and dispersed hydrocarbons. The inward pull causes water and product to move toward the Ferret inlet, enhancing recovery. Once the product/water mixture is taken inside the Ferret inlet, separation takes place; specific gravity is used to split the hydrocarbons and water into separate pumping paths.

The Ferret is recommended for liquids with kinematic viscosities greater than or equal to 4 centistokes (cst) at 55°F. Compatible liquids include fresh gasoline, JP4, JP5, kerosene, diesel

fuel, #2 fuel oil. Incompatible liquids include #3 (and above) fuel oil, SAE 10 (and above) motor oil, and hydraulic fluids. The Tygon tubing in the in-well separator is compatible with most hydrocarbon fuels but may be attacked by high concentrations of methyl ethyl ketone, acetone, other ketones, and some alcohols.

All information was provided by the vendor and has not been independently verified.

Technology Costs
No available information.

T0636

Quad Environmental Technologies Corporation

Chemtact Gaseous Waste Treatment

Abstract
The Chemtact™ gaseous waste treatment technology uses a gas scrubber to remove gaseous organic and inorganic compounds from airstreams using gas–liquid contact. Its potential applications include the treatment of off-gases produced by air stripping, soil aeration, incinerators, and thermal desorbers.

RIMS was unable to contact the vendor. The commercial availability of this technology is unknown.

Technology Cost
There is no available information regarding the costs associated with this technology.

T0637

R.C. Costello and Associates, Inc.

Actopentin Biomass Filter

Abstract
The Actopentin® biomass filter is an ex situ filter support for gas-phase bioremediation. The biomass filter is a proprietary and patented mixture of grape seeds, minerals, and other additives.

According to the developer, the technology can treat the following organic solvents: alcohols, ketones, aromatic hydrocarbons, ethers, esters, aldehydes, carboxylic acids, thioethers, mercaptans, and amines.

All information is supplied by the vendor and has not been independently verified.

Technology Cost
No available information.

T0638

R.E. Wright Environmental, Inc.

Steam-Enhanced Recovery

Abstract
Steam-enhanced recovery is an in situ process for the removal and recovery of petroleum from soil and groundwater. The technology injects steam into the subsurface to increase the solubility and mobility of petroleum, which is then pumped to the surface via a centrally located recovery well.

According to the vendor, the steam-enhanced recovery system can treat soils and groundwater contaminated with high viscosity petroleum products including unrefined petroleum, lubricating oils, fuel oils, polychlorinated biphenyls (PCBs), and coal tar. This technology is applicable for the remediation of contaminated areas within petroleum refineries. This technology, however, is no longer commercially available from this vendor.

The technology is best suited for coarse-textured soils that have a moderate to high hydraulic conductivity. The steam extraction system is not applicable for soil contaminated with metals or other inorganic wastes. The system is also not applicable for organics in which the mobility is not increased with elevated temperatures.

The generation of steam necessary for the remediation system may be cost prohibitive where small volumes of soil and water are contaminated.

Technology Cost

The vendor-supplied cost of a pilot-scale field demonstration using steam-enhanced recovery was $160 per ton in 1995 (D103822, p. 10).

The vendor estimates the price range to be between $30 and $60 per ton of waste treated (D103822, p. 13).

Information Source

D103822, VISITT 4.0, July 1995

T0639

R.E. Wright Environmental, Inc.

In Situ Bioremediation Treatment System

Abstract

The in situ bioremediation treatment system is an in situ bioremediation technology for the treatment of soils contaminated with organic compounds. According to the vendor, contaminated soils are remediated by stimulating the activity of indigenous soil microbes through the introduction of essential nutrients including anhydrous ammonia, an easily oxidized co-substrate (methane) and an electron acceptor (oxygen).

According to the vendor, the in situ bioremediation treatment system is applicable to soils contaminated with volatile organic compounds (VOCs) and semivolatile compounds, including those comprising various fuels, hydrocarbons, and solvents. The use of methane as an easily oxidized co-metabolite makes the technology amenable to treating soils contaminated with halogenated hydrocarbons.

Technology Cost

According to the vendor, the total cost for treating an estimated 9800 m^3 of contaminated soil at the Sweden 3 Chapman site, in Sweden, New York, for a 12-month duration was $\$52/m^3$ of soil (D18722Y, p. 134). Soil at this site was contaminated with trichloroethene (TCE), tetrachloroethene (PCE), acetone, methylethyl ketone (MEK), methyl isobutyl ketone (MIBK), toulene, and xylene.

Information Source

D18722Y, North Atlantic Treaty Organization, June 1998

T0640

Radian International, L.L.C.

Aeration Curtain

Abstract

The aeration curtain is an in situ treatment technology consisting of a trench filled with porous media within which an air sparging/soil vapor extraction (AS/SVE) system is installed. This technology has been used to remove trichloroethene (TCE) from groundwater. According to the vendor, this technology has the following advantages:

- A trench provides superior capture of a large plume for plume containment purposes.
- A trench can be uniformly backfilled with porous gravel, thereby reducing the impacts of preferential channeling in the zone of sparging and encouraging uniform and substantial mass transfer.
- The highly porous backfill material encourages vertical transport of the air within the trench, reducing the potential for lateral dispersion of air and contaminants into the adjacent formation.

This technology is not currently commercially available.

The primary disadvantage of an aeration curtain is that contaminated soil must be excavated during construction of the curtain.

Undegraded biopolymer slurry material remaining after trench construction may initially interfere with operations. Possible siltation interferences can prevent collection of samples from piezometers. A rise in upgradient water levels can result in potential blockage of groundwater flow, suggesting that airflow should be pulsed to allow for contaminated water to flow through the system.

Technology Cost

According to the vendor, cost for a 400 × 30 × 3-ft aeration curtain with soil vapor extraction of off-gases is approximately $1.2 million. In general, costs are very site specific (personal communication: Paul Bitter, Radian International, L.L.C., 1997).

T0641

Radian International, L.L.C.

AquaDetox/Soil Vapor Extraction (SVE)

Abstract

The AquaDetox™/SVE unit is an integrated technology for on-site treatment of contaminated groundwater and soil gas. It uses a moderate-vacuum, steam stripping system to treat extracted groundwater and an SVE system with granular activated carbon beds to treat extracted soil gas. Together, the units form an integrated, closed-loop system with no emissions and very high contaminant-extraction rates.

This system is designed to treat volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) at very high concentrations, which traditional nonvacuum air stripping

devices cannot adequately process. The AquaDetox/SVE unit is commercially available and has been used in several full-scale cleanups at sites around the country.

AquaDetox/SVE technology has the following advantages:

- Produces no hazardous air emissions; therefore, no air permit is required.
- Eliminates costly granular activated carbon replacement.
- Treats very high VOC concentrations [over 200,000 parts per million (ppm) in groundwater, and up to 12,000 ppm in soil vapor]
- Recovers solvent as liquid phase.

System limitations include:

- Alkalinity of the influent groundwater can affect performance.
- Site-specific conditions such as soil grain size, moisture content, porosity, stratification, and permeability are the most important properties that can limit the efficiency of treatment.
- Climactic conditions can also affect the performance of the stripping unit.

Technology Cost

In 1991, the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration program evaluated the AquaDetox/SVE system. The demonstration took place at the San Fernando Valley Groundwater Basin Superfund site in Burbank, California. Based on this demonstration, cost estimates for a full-scale deployment of the system were prepared. Three treatment flow rates were evaluated, based on the 1200-gallon-per-minute (gpm) system used at the Lockheed site: 500, 1000, and 3000 gpm. Capital costs and annual operational and maintenance (O & M) costs were estimated in 1991 dollars and are shown in Table 1.

A detailed breakdown of specific costs is available on page 22 of D104552. Monthly operating costs at the Lockheed site in Burbank, California, were estimated to be $30,700. This translates to a unit cost of $0.71 per 1000 gal of influent treated (D104552, p. 41). Steam at the Lockheed site cost about $14,700 per month; antiscaling chemicals cost $1800 per month; and the system used approximately $4200 of electricity per month. Labor costs varied, as progressively fewer personnel were needed to operate and maintain the system (D11229Y, p. 599).

Many factors can influence the cost of SVE-based treatments. Soil properties that can affect SVE costs include permeability, porosity, depth and stratigraphy of the contamination, site heterogeneity, and seasonal water table fluctuations. In general, the more permeable and homogenous the soil, the more efficiently SVE will operate, and the lower the treatment costs will be (D22449H, p. 4-4).

Contaminant properties can also affect treatment costs. The type and amount of contaminants will impact the efficiency of SVE, the number of extraction wells, the power of the blower unit,

TABLE 1 Estimated Costs for AquaDetox Based on the Lockheed Site in Burbank, California

	Treatment Flow Rate		
Cost Category	500 gpm	1000 gpm	3000 gpm
Capital	$3,200,000	$4,300,000	$6,000,000
Operation/maintenance	510,000	820,000	2,000,000

Source: (D104552, p. 22).

and the length of operation required to achieve project goals. It will also impact the type of ancillary technology(ies) selected (D22449H, p. 4-4).

In 2001, EPA published a cost analysis of various remediation technologies, including SVE. SVE technology costs were analyzed based on O & M costs, capital costs, and other site-specific data (D22449H, p. 4-1). EPA stated that there was a correlation between SVE unit costs and the volume of soil treated. SVE was demonstrated to have a measurable economy of scale. Unit costs for the treatment of less than 10,000 yd^3 of soil ranged from \$60 to \$350/yd^3. Unit costs for applications treating more than 10,000 yd^3 of soil were as low as \$5/yd^3 treated. A similar correlation was noted for unit costs versus mass of contaminants removed. Unit costs for projects with less than 3000 lb of contaminants requiring removal ranged from \$300 to \$900/lb. Unit costs for larger projects were less than \$15/lb, and costs for treating over 500,000 lb of contaminant were less than \$2/lb (D22449H, pp. 4–1, 4–4).

Information Sources

D104552, U.S. EPA, 1991

D11229Y, Derammelaere and Helgerson, 1990

D22449H, U.S. EPA, 2001

T0642

Recol Engineering, Ltd.

RYMOX Technology

Abstract

The RYMOX technology is a bench-scale technology intended to treat soils and other granular substances contaminated with petroleum products, PCBs, insecticides and other familiar, hazardous natural and man-made organic chemicals. ANI-Recol, Inc., began the development process that has subsequently been taken over by Recol Engineering, Ltd., as an alternative to current ex situ thermal technologies, namely incineration.

The RYMOX technology consists of mixing contaminated soils with unslaked lime, and progressively heating the mixture while adding a controlled amount of oxygen. The contaminants are vaporized, hydrolyzed, pyrolyzed, and oxidized. Hydrocarbons are converted to innocuous residues such as water, carbon dioxide, and a variety of gases. The cumulative advantage of this process is the benign effluent stream, which requires no further treatment.

Currently, a small pilot-scale study is under way, and a 2-ton (1.8-metric ton) per hour commercial demonstration is under design for treating soils contaminated with hydrocarbons or hazardous organic residues. This technology is not yet commercially available, and Recol Engineering, Ltd., is interested in pursuing joint ventures or demonstration projects.

Technology Cost

This is a new, developmental stage technology, and very little has been written about it. There is no cost information available at this time.

T0643

Recra Environmental, Inc.

Mini-Miser

Abstract

The Mini-Miser dewatering system uses hydraulic pressure to mechanically extract liquids from sludges, sediment, and solids. The system incorporates a patented press design that has previously

been used for the extraction of fruit and vegetable juices. This design allows for the dewatering of materials with varying particle sizes and viscosities, including nonpumpable solids and sludges as well as material containing grit, gravel, vegetation, or debris. The unit can operate as a secondary dewatering unit for municipal wastewater treatment plant applications or as an alternative to filter presses, sludge drying beds, and thermal dryers.

The Mini-Miser was designed to handle materials containing relatively high solids (greater than 15%), such as slurries and sludges. Successful pressing of sludges with 2 to 5% solids has been demonstrated. Waste materials with very low solids content may require long pressing cycles due to difficulty in forming a cake. Freezing temperatures will impair processing.

The Recra Mini-Miser is manufactured by Good Nature Products of Buffalo, New York, for use as a cider press. Recra Environmental markets the Mini-Miser specifically for dewatering.

Technology Cost

The costs of the Mini-Miser dewatering systems (MMDS) are as follows:

- DC200 $75,000
- DC280 $140,000
- DC360 $225,000
- DC450 $290,000

Prices for specific units will vary based on the level of customization needed to integrate the MMDS into the solids management system. A mobile DC200 is available for rent at $400 per week. A mobile DC360 is available for $1500 per week (personal communication: Kenneth Kinecki, Recra Environmental, Inc., 1996). The estimated price for treatment is $1 to $5 per ton (D103811, p. 15).

Information Source

D103811, VISITT 4.0, 1995

T0644

Recra Environmental, Inc.

Alternating Current Electrocoagulation

Abstract

Alternating current electrocoagulation (ACE) is an electrochemical treatment technology where aluminum polyhydroxide species are introduced into aqueous media to remove suspended solids, oil droplets, and soluble ionic species. This technology enhances the filtration and dewatering rates of solids removed from an effluent.

Liquid–liquid and solid–liquid phase separations are achieved that produce sludges that are more easily filtered compared to chemical flocculent addition. This technology enhances the filtration and dewatering rates of solids removed from an effluent. The vendor states that this technology is commercially available; however, the technology has not been demonstrated at full scale for Superfund site remediation.

Successful commercialization of the technology requires further research to significantly improve aluminum dissolution efficiency. If the ACE Separator™ can be engineered to regularly

generate sufficiently high aluminum dissolution concentrations, the technology may be applicable to industrial effluent treatment trains, as well as for some Superfund site remediation activities.

According to the vendor, recent work has been accomplished regarding the aluminum dissolution efficiency. The fluidized-bed system has a dissolution factor 10 times (10×) that of the parallel electrode system. The parallel electrode system is no longer offered commercially by Recra Environmental, Inc., but remains available for testing purposes.

Technology Cost

Based on results from a field demonstration to enhance titanium dioxide recovery in the production of high-grade titanium dioxide pigment, treatment costs (including electrical power, aluminum pellets, and labor) to achieve an 85 to 90% recovery of titanium dioxide from an influent stream of 1100 mg/liter of titanium dioxide was estimated to be \$0.10 to \$0.15 per 1000 liter of overflow (D121573, p. 788).

Based on bench- and pilot-scale studies, capital cost for a standard ACE separator with a nominal throughput of 190 liters/min (50 gpm) is estimated to \$80,000, and for a 950 liter/min (250 gpm) unit, \$300,000. The degree of automation, control systems, specialized materials, and the need for electrical transformation can effect the total capital cost (D121573, p. 788).

As cited in the June 1997 *The Hazardous Waste Consultant,* capital costs for an ACE system range from \$16,000 for a 10-gpm system to \$130,000 for a 100-gpm system (D169588, p. 4.11).

The operating cost (electricity, aluminum pellets, operation and maintenance) for the treatment of several waste types tested at the bench- and pilot-scale levels were developed using the cost for alum treatment (\$0.79 per 1000 liters) as the basis. Table 1 presents the results of these comparisons, as well as information provided by the vendor on a wide range of contaminant waste streams (D121573, p. 788).

Information Sources

D121573, Barkley et al., 1993

D169588, The Hazardous Waste Consultant, 1997

TABLE 1 Operating Costs of Alternating Current Electrocoagulation Treatment

Waste Type	Operating Costs (Dollars per 1000 Liters)
Dilute clay–water Suspensions	0.13–0.26
Oily emulsions containing surfactants and/or stabilizers	1.30–2.60
Anodization rinse water	0.22–0.30[a,b]
Anodization wastewater phosphoric/sulfuric acid rinse	0.35–0.45[b]
Foundry wastewater solids/oil and grease	0.40–0.50[b]
Compost runoff/leachate solids, COD/BOD[c] loading, phosphorus	0.60–0.68[b]
Casting waste—quench water solids, oil and grease, metals	0.31–0.35[b]
Textile dyeing wastewater solids, color, COD/BOD loading	0.42–0.50[b]
Oily emulsions without surfactants	0.40–0.55[a,b]

[a] Treatment costs varied, but typically were less than or equal to that of alum treatment.
[b] All operating cost based on \$0.10/kW, \$1.50/lb of conditioned alumina pellets, and labor costs of \$30/hr. Vendor-supplied values.
[c] COD = chemical oxygen demand; BOD = biological oxygen demand.

T0645

Recycling Sciences International, Inc.

Desorption and Vapor Extraction System

Abstract

The desorption and vapor extraction system (DAVES) uses a low-temperature fluidized bed to remove volatile and semivolatile organics such as polychlorinated biphenyls (PCBs), polynuclear aromatic compounds (PAHs), pentachlorophenol (PCP), volatile inorganics (tetraethyl lead), and some pesticides from soil, sludge, and sediment. The process generally treats waste containing less than 10% total organic contaminants and 30 to 95% solids. The process does not treat nonvolatile inorganic contaminants such as metals.

This technology was accepted into the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration program in April 1995. According to the vendor, the technology is commercially available.

Technology Cost

In general, it is not possible to differentiate among the thermal desorbers based on cost. The costs are scale dependent, ranging from $90 to $130 per ton ($99 to $143 per metric ton) for a 1000-ton (907-metric ton) site to $40 to $70 ($44 to $77 per metric ton) for a 10,000-ton (9070-metric ton) site for mobile systems treating petroleum-contaminated soils and from $300 to $600 per ton ($331 to $661 per metric ton) for a 1000-ton (907-metric ton) site to $150 to $200 ($165 to $220 per metric ton) for a 10,000-ton (9070-metric ton) site mobile system operating at a Superfund site. Matrix moisture and contaminant type are critical parameters in analyzing desorption costs (D12901B, p. 2.5).

Information Source

D12901B, Anderson, 1993

T0646

RedZone Robotics, Inc.

Houdini

Abstract

RedZone Robotics, Inc., has developed Houdini, a compact, tethered, track-driven work platform for radioactive waste retrieval operations. The vehicle is designed with a folding frame chassis that can fit through an opening as small as 22.5 inches in diameter. The unit comes with a retractable plow blade and onboard manipulator; other specialized tools can be added for specific applications.

The vendor claims that Houdini is qualified for a number of waste remediation applications. Uses for Houdini include mechanical waste retrieval, hot cell decommissioning, tank decontamination, material containerization, wall scabbling, tank inspection, pipeline cleaning and repair, and ship and barge cleaning.

RedZone claims the following advantages of Houdini:

- Retrieves wastes from tanks for treatment and long-term storage and can remove debris to clean areas after removal by other methods.
- Tracked locomotion enables travel on, over, or through materials.

- Smooth surfaces and no entrapment corners allow for easy decontamination by spray wash down.
- System is sealed and can operate when fully submerged.

Special power and communications lines, access ways, and deployment equipment may be necessary. Extensive training is required if the robot is to be operated and/or maintained by site personnel. Some exposure of personnel may be necessary to decontaminate the equipment prior to storage. Removed materials will require treatment or stabilization using some other remediation technology prior to disposal.

Technology Cost
In 1997, the U.S. Department of Energy (DOE) announced that the Houdini robot, in conjunction with another robotics technology, the light-duty utility arm (LDUA), had successfully removed tank sludge from a gunite tank at the Oak Ridge DOE facility. According to the project manager, cleaning the radioactive wastes from one gunite tank was estimated to cost approximately $1 million. The project costs of remediating eight gunite tanks at the Oak Ridge facility, from initial surveys through ultimate disposal, are estimated to be $66 million (D17132E, pp. 2–3).

The use of the remotely operated Houdini system allows for significant reductions in worker exposure to radioactivity. In fact, according to the DOE, a standard cost analysis of the Houdini system as compared to baseline technologies is not possible because Houdini is used in situations where there are no legitimate alternative approaches available. The DOE estimates that the return on the $4 to $5 million investment in Houdini technology can be as high as 10 to 1 at the Oak Ridge site alone; the technology's use at other DOE sites would yield additional cost savings (D188094, p. 16).

Information Sources

D17132E, The Oak Ridger Online, 1997
D188094, U.S. DOE, 1998

T0647

RedZone Robotics, Inc.

Rosie

Abstract
RedZone Robotics, Inc., has developed Rosie, a multipurpose decontamination and dismantlement (D & D) robot for use at hazardous and radioactive waste sites. Rosie is a large-scale, construction-grade, remotely operated workstation capable of tearing a building down from the inside out. Rosie consists of three main components: the console, the power distribution unit, and the robot. The robot combines a locomotor unit with a heavy manipulator. The unit weighs roughly 14,500 lb, can support a payload of up to 2000 lb, and has an effective reach of 27 ft. Rosie is being evaluated in a series of endurance tests at Oak Ridge National Laboratory in Oak Ridge, Tennessee. Rosie technology has also been deployed to assist in decommissioning the CP-5 research reactor facility at the Argonne National Laboratory in Chicago, Illinois. After completion of that project, Rosie will be used at several other DOE and U.S. Department of Defense (DOD) sites, including some that date back to the Manhattan Project. The technology is commercially available.

RedZone claims the following advantages of using robots:

- Workers are removed from radiation areas reducing exposures.
- Higher than expected exposure rates do not greatly increase costs.

- Fewer personnel (radiation workers and support personnel) are required.
- Tasks can be done that are impossible for workers to accomplish manually.
- Improved waste segregation and decontamination and decrease in need for personal protective equipment leads to a decrease in the amount of waste that must be transported and disposed.

Special power and communications lines, access ways, and deployment equipment may be necessary to use. Extensive training is required if the robot is to be operated and/or maintained by site personnel. Some exposure may be necessary to decontaminate the equipment prior to storage. Removed materials will require treatment or stabilization using some other remediation technology prior to disposal.

Technology Cost

In 1996, a basic Rosie unit was reported to cost approximately $750,000. Optional equipment available at increased cost included additional shielding, and the option of a hydraulic or an all-electrical unit. The vendors state that the technology may be attractive to a service provider industry using Rosie on several decontamination and decommissioning sites within a region, thus enabling the owner to amortize costs (D149875, p. 83). In 1997, the company stated that it expected to sell three to four units per year (D17884B, p. 3).

The vendor also states that Rosie could be cost effective as an emergency response system. For comparison, the vendor states that the cleanup activities from the Chernobyl incident currently account for 15% of the Ukraine's annual budget, and that the construction cost estimates for a second protective "sarcophagus" at the Chernobyl site range from $10 million to $15 billion (D149875, p. 83). According to the vendor, the standard evaluation of costs associated with personnel exposures range from $5000 to $20,000 per person rem at U.S. power plants. In some cases, remote applications may be more cost effective than manual activities (D149795, p. 1).

Information Sources

D149795, Nuclear Engineering International, 1995

D149875, Charles, 1996

D17884B, Vargo, 1997

T0648

Refranco Corporation

Sustained Shock Thermal Plasma

Abstract

Refranco Corporation (Refranco) has developed sustained shock thermal plasma (SSP) technology for the ex situ treatment of hazardous wastes. The technology uses a combination of electrodes to form a nonequilibrium plasma that distributes the thermal load between the waste particles during treatment. A commercial pilot facility treat municipal solid waste, ashes, oil, and sewage sludge has been built in Singapore. The technology is commercially available.

According to the vendor, SSP technology offers several advantages, including ease in processing off-gases, high electrical efficiency, and operational flexibility.

Large particles cannot be processed by the technology. If the reactor is operated, at even 20% of its nominal power, without input of feedstock, the lining of the reactor may absorb the energy released by the plasma, causing it to melt or shatter.

Technology Cost
No available information.

T0649

Regenesis Bioremediation Products, Inc.

Hydrogen Release Compound (HRC)

Abstract
Regenesis Bioremediation Products, Inc., offers a proprietary Hydrogen Release Compound (HRC™) as a method of increasing the in situ anaerobic degradation of chlorinated aliphatic hydrocarbons (CAHs). HRC is a polylactate ester formulated to release lactic acid upon hydration. The lactic acid is metabolized by anaerobic microbes. This process releases hydrogen gas that is used by reductive dehalogenators to dechlorinate the targeted hydrocarbons. The technology has been field tested and is commercially available.

Regenesis claims HRC has the following advantages:

- Provides a constant and persistent source of hydrogen.
- Avoids introduction of oxygen that can occur with other hydrogen injection methods.
- Promotes desorption of chlorinated aromatic hydrocarbons.
- Minimizes site disturbance.
- Eliminates continuous operation of pumping equipment, dramatically reducing operations and maintenance (O & M) costs.

HRC technology may generate hazardous daughter products that may require significant time to remediate under anaerobic conditions.

Technology Cost
According to the vendor, using HRC to treat a site contaminated with "a half drum of spilled PCE [tetrachloroethene]" would cost approximately $50,000. The vendor estimate is based on two injections, which were $10,000 each, and the cost of HRC product, which was $15,000 for each injection. This scenario assumes a spill area of 180 by 20 ft and a PCE/trichloroethylene (TCE) concentration of 8000 parts per billion (ppb) (D203816, p. 9).

HRC was used in a pilot-scale test as part of the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) Emerging Technology Program (D18866D, p. 24). The evaluation took place at a former industrial facility in Watertown, Massachusetts, contaminated with TCE, PCE, and vinyl chloride (VC). Costs for the pilot project were less than $30,000, including expenses associated with analysis and monitoring. It is estimated that a full-scale application of HRC at the site would cost less than $50,000. This estimate does not include expenses associated with long-term sampling, analysis, and reporting (D19522W, p. 125).

HRC was used to treat PCE contamination at a dry cleaning facility in Florida as part of a large-scale demonstration project. One-hundred forty-four direct-push points, which were spaced 10 ft apart, were used to inject 6,800 lb of HRC. Total demonstration costs were $127,000, including $27,197 used to purchase the HRC product (D21482E, pp. 7, 8; D21289F, p. 4).

In 1999, HRC was used with other treatment technologies at a brownfield site in Aurora, Colorado. An in situ air sparge/soil vapor extraction system was first used at the site to treat TCE contamination; however, additional measures were needed to prevent the migration of PCE off-site. After an unsuccessful application of zero-valent iron injection, 240 lb of HRC were injected at five locations by direct-push methods. Total project costs were $110,000, which included expenses for instruments ($30,000), consumables ($1000), labor ($69,000), and waste disposal ($10,000) (D22019Z, pp. 2, 3).

At a dry cleaning facility in Hayden Island, Oregon, HRC was used to treat PCE-contaminated groundwater. The remediation project, which was funded by the Oregon Dry Cleaner Program, involved the application of 1680 lb of HRC at 34 injection points (48 lb of product per point). Total costs at the site were $31,000, including $14,000 for HRC product (2310 lb, priced at $6/lb), $900 for pump rental, $2000 for bench tests, $4000 for drilling activities, and $10,000 for monitoring (over four quarters). These costs do not include expenses associated with site investigation, additional contractor activities, and government oversight (D212828, pp. 1, 3, 7).

HRC was applied at a former filter-manufacturing site in Rochester, New York. Several remediation technologies, including shallow soil excavation, multi-phase high vacuum extraction, and 2-PHASE extraction, had been applied. HRC was injected at 21 points using Geoprobe direct-push methods. Approximately 35 lb of product were applied at each point (D21287D, pp. 1–5, 8). According to Boyle and Koenigsberg (1999), the use of HRC over alternate technologies saved the site owner $25,000. Based on the diminishing returns of the 2-PHASE system installed at the site, earlier use of HRC could have saved the owner $140,000 (D200691, p. 43).

Information Sources

D18866D, Regenesis, undated vendor web page
D19522W, Dooley et al., 1999
D203816, U.S. EPA, 1999
D200691, Boyle and Koenigsberg, 1999
D22019Z, U.S. EPA, undated
D21287D, Boyle et al., undated
D21289F, Lodato et al., undated
D212828, Anderson et al., undated
D21482E, U.S. EPA, 2000

T0650

Regenesis Bioremediation Products, Inc.

Oxygen Release Compound (ORC)

Abstract

Regenesis Oxygen Release Compound (ORC®) is a commercially available, in situ or ex situ biological treatment technology for soil and groundwater contaminated with petroleum hydrocarbons. ORC is a proprietary form of magnesium peroxide that releases oxygen for up to a year and has proven effective as a method of increasing dissolved oxygen in contaminated media. The increase in dissolved oxygen results in accelerated biodegradation by naturally occurring hydrocarbon-degrading microorganisms. ORC can be used in powder or briquette form to release oxygen to groundwater or soil contaminated with petroleum hydrocarbons.

The technology can be used for the passive in situ treatment of groundwater via exchangeable filter socks placed in trenches or wells, or via a cement slurry injected into the aquifer to form a migration barrier across the plume of contamination, or as a source control. OCR can also be used in powder form for the in situ or ex situ treatment of soils. The primary in situ soil application is the treatment of underground storage tank (UST) removal excavations. The technology can also be used to treat soils in ex situ biopiles.

Because ORC is a passive treatment technology, it is virtually maintenance free. There are no mechanical components to maintain, and, once installed, the compound needs to be replaced only once every 4 to 6 months. Treatment costs of remediating a source area may be reduced by placing ORC in wells downgradient from the source. In some cases, ORC can be placed in existing wells, further reducing costs.

Technology Cost

In September, 1996, the cost of bulk ORC powder was $9.75/lb. The cost of filter socks containing a 50% ORC mixture was $60.00 for a 6-inch-inside diameter well, $35.00 for a 4-inch-inside diameter well, and $17.50 for a 2-inch-inside diameter well (D13823I). The number of filter socks needed depends on the extent of contamination. At a former service station in Belen, New Mexico, 342 filter socks were loaded into 20 wells (D13584M).

Costs for constructing 22 ORC barrier wells circa 1994 was $15,000. The ORC concrete in the wells is replaced every 5 to 6 months at an estimated cost of $3000 per year for the ORC (D12995X, p. 266).

A cost comparison between ORC, pump and treat, and air sparging with soil vapor extraction (SVE) is presented in Table 1. The costs given are for a site in Oklahoma with a plume width of 60 ft, a treatment area of 9146 ft^2 and a treatment thickness of 11 ft. The peak BTEX (benzene, toluene, ethylbenzene, and xylenes) load was 25 parts per million (D13823I; D14008Z).

Treatment costs of remediating a source area may be reduced by placing ORC in wells downgradient from the source. In some cases, ORC can be placed in existing wells, further reducing costs (D13582K, p. 102).

Information Sources

D12995X, Kao & Borden, 1994

D13823I, Regenesis Bioremediation Products, date unknown

D13584M, Johnson & Methvin, September 1996

D13582K, Brown et al., Remediation/Summer 1996

D14008Z, Regenesis Bioremediation Products, date unknown

TABLE 1 ORC Saturated Zone Source Treatment versus Pump and Treat and Air Sparging with Soil Vapor Extraction (SVE) in Dollars[a]

Cost Category	ORC	Pump and Treat	Air Sparging w/SVE
	System Installation		
ORC	$11,943	N/A	N/A
Geoprobe®	11,168	N/A	N/A
Labor/materials	5,220	$40,098	$49,734
Capital equipment	0	84,612	36,800
Subtotal	$28,331	$124,710	$86,534
Monitoring	11,055	40,200	40,200
System maintenance	6,900	152,400	32,100
Total	$46,286	$317,310	$158,834

Source: From D13823I & D14008Z.

[a] The ORC system is designed to treat a plume with a peak BTEX concentration of 25 ppm and close the site in 1 year. The values for the air sparging system were derived independently by the site consultant and site closure is expected in 3 years (D13823I).

T0651

Remedial Concepts, L.L.C.

DECHLOR #108 Solution

Abstract

DECHLOR #108 is a solution that has been developed for use in treating chlorinated solvents in waste oil. According to the vendor, the solution displaces chlorine molecules and converts them into nontoxic substances, while leaving the waste oil supply unaffected.

According to the vendor, this product is relatively new, and further analyses is currently being performed. DECHLOR #108 is commercially available from Remedial Concepts, L.L.C.

All information contained herein has been supplied by the vendor and has not been independently verified.

Technology Cost

No available information.

T0652

Remedial Concepts, L.L.C.

STC Bison #308 and #508

Abstract

STC Bison #308 and #508 are solutions for treating oil and grease contaminants. According to the vendor, they can neutralize petroleum-based oil and grease by converting petroleum hydrocarbons into nontoxic soaps through a saponification process. Further, the vendor states that STC Bison #308 and #508 solutions can be used to remediate hydrocarbon-contaminated soils. Remedial Concepts claims that the oils and greases are converted into cleaners and detergents that are safe enough for disposal into any sewage system

The vendor claims that the solution:

- Saponifies oils, turning them into water-soluble, nontoxic detergents.
- Chelates heavy metals.
- Prevents or extinguishes combustion of flammable hydrocarbons.

According to the vendor, the STC Bison #308 and #508 solutions have been laboratory tested. The solutions are commercially available from Remedial Concepts, L.L.C.

Technology Cost

According to the vendor, STC Bison #308 and #508 are available in the following quantities:

1 gal: $23.75
5 gal: $118.75
55 gal: $1306.75

Sample sizes may be obtained from the vendor at no charge (D16802P, p. 6).

Information Source

D16802P, Remedial Concepts, L.L.C., 1997

T0653

Remediation of Perchlorate — General

Abstract
Perchlorate is the oxidation product of chlorate. It forms a variety of compounds, including ammonium perchlorate, potassium perchlorate, sodium perchlorate, and perchloric acid. Perchlorate is highly reactive in its solid state, and as ammonium perchlorate it is used as the oxidizer in solid rocket fuel. Because of its limited shelf life, it must be periodically washed out of the country's rocket and missile inventory and replaced. Large volumes of the chemical have been disposed of since the 1950s, and perchlorate has been detected in large concentrations in both groundwater and surface water. Perchlorate has also been used in the manufacture of matches, munitions, fireworks, and in analytical chemistry.

Region 9 of the U.S. Environmental Protection Agency (EPA) first became aware of potential contamination issues surrounding perchlorate in 1985, when perchlorate was detected in a monitoring well at concentrations of up to 2.6 parts per million (ppm). By 1999, perchlorate releases had been confirmed in 15 states. Research is ongoing to determine the risks associated with perchlorate contamination.

Because perchlorate is nonvolatile and highly soluble in water, it cannot be removed from water by conventional water treatment technology. Currently, there is an effort to develop technologies that can remove perchlorate from contaminated water.

There are no tested full-scale perchlorate removal systems currently available. Bench-scale and pilot-scale testing is currently underway in several areas. Treatment options currently under study involve:

- Physical processes, including ion exchange technology for contaminated water
- Chemical processes, including catalytic reduction and peroxide/carbon treatment for wastewater
- Thermal processes, including supercritical water oxidation and incineration for solid perchlorate
- Biochemical processes, including biochemical reduction for contaminated groundwater
- Phytoremediation processes, using plant species such as parrot feather (*Myriophyllum aquaticum*)

Technology Cost
There are many variables associated with estimating the cost of perchlorate contamination. For many commercially available systems, cost data is estimated based on pilot- or bench-scale tests. These estimates may not include secondary contaminant disposal costs or other costs of operation. Costs are also likely to vary considerably based on site-specific conditions such as contaminant concentrations, additional contamination, treatment volumes, and treatment rates.

Based on the result of bench- and pilot-scale testing, cost estimates were determined for Krudico, Inc., ion exchange system treatment of groundwater contaminated with nitrate and perchlorate at the U.S. Department of Energy's (DOE's) Lawrence Livermore National Laboratory. Costs were estimated to cover three options: nitrate removal only, perchlorate removal only, and removal of both nitrate and perchlorate. The proposed treatment system would treat approximately 1,839,600 gal of contaminated groundwater at a treatment rate of 3.5 gallons per minute (gpm). Nitrate removal was estimated to cost \$0.15/gal, perchlorate removal was estimated at \$0.02/gal, and a combined removal system was estimated to cost \$0.16/gal (D20493D, p. 12).

Researchers stated that ion exchange removal of nitrate was cost prohibitive at this site due to the high cost of waste disposal. They concluded that the perchlorate-only alternative was the most cost-effective solution. Under this scenario, nitrate would be removed by another remediation technology. Perchlorate disposal costs under this option were \$350/year, and minimal

TABLE 1 Summary of Costs (in Dollars) Associated with Various Treatment Alternatives at Lawrence Livermore National Laboratory

Option	Capital Costs	Setup/ Installation Costs	Operation and Maintenance (O & M) Costs	Cost per Gallon Treated (Overall)
Nitrate removal only	\$15,700	\$25,600	\$258,400	\$0.15
Perchlorate removal only	\$2,300	\$4,300	\$37,200	\$0.02
Removal of nitrate and perchlorate	\$17,700	\$27,600	\$263,300	\$0.16

Source: Adapted from D20493D.

TABLE 2 Cost Information for an Integrated ISEP® Rayox System

	System Specifics
Treatment rate	1,500 gal/min
Influent nitrate concentration	Perchlorate 18–76 ppb, *N*-nitrosodimethylamine (NDMA) not specified
Secondary waste generated	16,200 gal/day
Treated water concentration	Perchlorate <4 ppb, NDMA <0.002 ppb
	System Costs
Unit costs	\$1,850,000
Installation costs	\$200,000–\$400,000
Operating costs	\$570,000
Building costs	\$90,000 (1,800 ft^2 at \$50/ft^2)
Waste disposal costs	Not provided

Source: Adapted from D20019R, Calgon Carbon Corporation, 1998.

maintenance of the treatment unit would be required (D20493D, p. 12). The cost estimates are summarized in Table 1.

In 1998, Calgon Carbon Corporation prepared an estimate for an integrated treatment system using ISEP® technology and another Calgon Carbon system (Rayox) to remove perchlorate and *N*-nitrosodimethylamine (NDMA) from contaminated groundwater in California (D20019R). This cost estimate is summarized in Table 2.

Information Sources

D20019R, Calgon Carbon Corporation, 1998

D20493D, Burge and Halden, 1999

T0654

Remediation Service, International

Internal Combustion Engine (ICE)

Abstract

Remediation Service, International manufactures internal combustion engine (ICE) systems that are used to destroy volatile organic compounds (VOCs) in contaminated soil. Vapors are extracted from the soil using the vacuum generated by the engine. The vapors are then burned as

fuel by the engine. The exhaust gases pass through a standard catalytic converter for complete oxidation before entering the atmosphere.

ICE technology is not designed to remove or treat chlorinated vapors that can produce an off-gas stream containing hydrochloric acid. This technology does not treat nonvolatile compounds or heavy metals. Areas with low-permeability soils where minimal flow rates are expected may not be appropriate for this technology.

Technology Costs

In 1994, purchase prices for ICE units ranged from $40,450 for Model VC2 to $98,880 for Model V4. Rental prices of VC2 and V3 units were estimated to be $220 per month and for the V4 systems were estimated to be $374 per month. According to an Air Force evaluation of the technology, renting units would be more practical for any application lasting less than 10 months (D179377, p. 4–2).

ICE technology was demonstrated at the U.S. Department of Defense's (DOD's) Patrick Air Force Base (AFB) in Brevard County, Florida. During the initial 2-day demonstration, daily costs ranged from $305 to $337 per day. During the 3-month evaluation of the technology, operating costs ranged from $74 to $107 per day. Propane costs accounted for $24 to $57 of the daily operating costs, and one hour of labor per day was required to check and monitor the units (D179377, p. 4–2).

During a pilot-scale test in 1993 at the DOD's Davis-Monthan AFB in Tucson, Arizona, a V2C internal combustion engine (ICE) was combined with a S.A.V.E.™ (spray aeration–vapor extraction) system to treat contaminated soil and groundwater. Based on a 90-day test, the unit operated at 20 to 30 standard cubic feet per minute (scfm) and removed 200 to 300 lb of volatile organics per day from the soil. The cost per pound of total volatile hydrocarbon (TVH) removed decreased from $1.12 to $0.49/lb over the 90-day test.

A full-scale, combined system was installed in July/August of 1995 at the same site. The system included six vapor extraction wells completed at varying depths to focus vapor extraction in the most contaminated soil intervals. Two eight-cylinder ICEs with a maximum flow rate range of about 300 to 500 standard cubic feet per minute (scfm) were used. Cost per pound TVH removed ranged from approximately $0.06 to $0.073 over the first 120 days of operation (D15758Y). During the 21-month run of the project, the unit removed more than 317,500 kg of TVH at an average cost of $0.31/kg (D18093S, p. 5).

At Bolling AFB in Washington, D.C., an ICE/S.A.V.E. system operated for 7 months and removed more than 21,300 kg of TVH at an average cost of $2.16/kg. After 4 months of operation at Williams AFB in Mesa, Arizona, the system had removed more than 90,700 kg of TVH at an average cost of $0.13/kg. At Luke AFB in Glendale, Arizona, a model V3 ICE and S.A.V.E. system removed 169,000 lb of TVH over a 2-month period at a cost of $0.23/lb. Higher costs for treatment generally indicate lower influent TVH concentrations and thus increased reliance on supplemental fuel sources (D18093S, p. 5; D17146K).

Information Sources

D15758Y, Archabal et al., 1996

D17146K, Archabal et al., 1997

D179377, Air Force Center for Environmental Excellence, 1994

D18093S, Guest and Ratz, undated

T0655

Remediation Service, International

S.A.V.E. System

Abstract

The S.A.V.E.™ (soil aeration–vapor extraction) technology combines air stripping, vacuum extraction, and combustion technologies for the remediation of soil, groundwater, and

TABLE 1 Examples of Treatment Costs

Site	Cost per Pound of TVH Removed	Months in Operation	Pounds TVH Removed
Davis-Monthan AFB	\$0.14	21	>700,000
Luke AFB	\$0.23	9	169,000
Williams AFB	\$0.06	4	>200,000
Bolling AFB	\$0.54	7	>47,000

Source: D17146K.

free-floating product. The system is designed to simultaneously remove hydrocarbon contamination from soil and groundwater. According to the vendor, the system also promotes bioremediation at a site by increasing oxygen levels in the soil and dissolved oxygen content in the groundwater.

The S.A.V.E. technology was developed to remediate problems caused by leaking underground storage tanks (LUSTs). The technology was patented by Remediation Services International. S.A.V.E. technology has been applied during full-scale remediation projects and is commercially available.

The S.A.V.E. technology is self-contained and equipped with a trailer-hitch mount for transportation. Hydrocarbon vapors recovered through the system's remedial actions are directed to the engine intake where they are burned as part of the normal engine combustion process, which often eliminates the need for process waste stream controls and external power sources. Emissions from the engine are passed through a small catalytic converter to maximize the destruction of removed hydrocarbons.

Technology Costs

At the Davis-Monthan Air Force Base in Arizona, a full-scale system removed over 700,000 lb of total volatile hydrocarbons (TVH) in a period of 21 months. The average cost was \$0.14/lb (D17189V, p. 1). Table 1 displays this cost and the average treatment costs from S.A.V.E. demonstrations at other U.S. Department of Defense (DOD) Air Force Bases. According to the vendor, higher costs represent lower influent total volatile hydrocarbon (TVH) concentrations and increased use of supplemental fuel as a result of decreasing extracted hydrocarbon concentrations (D17146K, p. 1).

An example of S.A.V.E. system costs comes from a remediation project conducted in Silver Springs, Nevada, between 1994 and 1995. Installation of the S.A.V.E. system at the site, including eight monitoring and soil vapor extraction wells, cost \$35,000. A S.A.V.E. II unit was purchased for \$72,000, and its direct operating costs over 10,182 hours of operation were \$29,000.

S.A.V.E. unit prices vary based on which features are required for the particular uses at individual sites.

Information Sources

D14472J, Henkle and Associates, undated

D17146K, Archabal et al., 1997

D17189V, Archabal et al., 1996

T0656

Remtech Engineers

Bubble Lance Low-Profile Diffused Air Stripper

Abstract

Remtech's Bubble Lance Low-Profile Stripper (BLLS) is a diffused air, shallow channel, low-profile air stripper. The BLLS is designed to reduce operation and maintenance costs for groundwater and wastewater cleanup over conventional diffused air or plate strippers.

According to the vendor, the system has the following features:

- Minimal clogging, simple cleaning and operation.
- Polyvinyl chloride (PVC) construction, fiberglass, and stainless steel also available.
- Modular system capacity 15 to 100 gal/min.
- No metals pretreatment required.
- Wastewater flows through system under hydrostatic heads.
- Radial and regenerative blowers.
- Trailer-mounted mobile treatment systems available.

This technology is currently commercially available.

Technology Cost

No available information on specific costs. Quotations are available for specific treatment system designs (personal communication: Mark D. Ryckman, Remtech Engineers, 1997). These designs vary based on the type of job required at a specific site.

The vendor claims reduced maintenance and life-cycle costs for the Bubble Lance system compared to deep diffused air strippers or plate strippers (D14634J).

Information Source

D14634J, Remtech Engineers, vendor literature

T0657

Resonant Shock Compaction, L.L.C.

Resonant Shock Compaction

Abstract

Resonant Shock Compaction (RSC) is an ex situ, volume reduction technology that uses vibration and compaction to stabilize soil, debris, and wastes contaminated with heavy metals and radionuclides. The influent media is packed into a mold and subjected to pressure and vibratory shock. The final product has a high, compressible strength and may be formed into different shapes and sizes.

The technology is available for commercial use and licensing as Resonant Shock Compaction through the Resonant Shock Compaction, L.L.C.

According to the vendor, the RSC system has several advantages:

- Demonstrates a high output capacity.
- Offers flexibility in the size and shape of the final product.
- Has a low capital equipment cost.
- Treats wastes on-site.

According to the vendor, the RSC process is effective with a waste loading of 85 to 100% by volume. The process is also capable of incorporating rubble and debris into the final product; however it is limited by the size and amount of rubble it can incorporate effectively.

Technology Cost

According to the inventor of the technology, an RSC facility capable of solidifying up to 200 tons of nonhazardous ash per day requires a capital investment of about $470,000. A fully automated facility designed to treat 200 tons of low-level or high-level radioactive waste per day costs about $5 million. Treatment costs would range from $100 to $200 per ton (personal communication: Keith Wier, 1997).

According to the vendor, the capital costs for full-scale plant designed to compact 100 tons of fly ash per 8-hr shift would be approximately $1,000,000. The operating costs were range from $100 to $500 per ton (D225058, p. 4; D225047, p. 2).

Information Sources

D225047, Goss et al., 1999

D225058, Amme et al., 1998

Personal communication, Keith Weir, 1997

T0658

Resource Management and Recovery

AlgaSORB

Abstract

AlgaSORB® is a biological sorption technology designed to remove heavy metals from aqueous solutions, particularly groundwater. The technology is based on the natural affinity of algal cell walls for heavy-metal ions. AlgaSORB takes nonliving algal biomass and immobilizes it in a silica gel polymer. This technology can use algae such as *Spirulina platensis* (a blue green alga) and *Cyanidium caldarium* (a red alga). The polymer is a hard material in which the cells are protected from decomposition by other organisms and that can be packed into columns in a pump-and-treat remediation system. AlgaSORB has been demonstrated on a pilot scale only and has not been used in several years.

AlgaSORB is most useful in groundwater treatment where target effluent levels for heavy metals are typically below 100 mg/liter. According to the vendor, this technology can remove aluminum, cadmium, chromium, cobalt, copper, gold, iron, lead, nickel, manganese, mercury, molybdenum, platinum, silver, uranium, vanadium, and zinc. The technology may also have applications treating industrial wastewater contaminated with heavy metals, such as electroplating plant waste waters.

Alkaline solutions are detrimental to the physical integrity of preparations containing *Spirulina* silica due to the propensity of silica gel to hydrolyze in alkaline solution. The addition of aluminum ions represents one approach for overcoming the instability of this algal silica polymer at high pH.

There is a significant loss of binding capacity for copper (as the amine complex) upon recycling the *Spirulina*-based polymer.

Technology Costs

The bounds of operating costs for a 600 gal/min (2300 liter/min) base system are \$0.31/1000 gal (\$0.08/m^3) for chromium and \$3.69/1000 gal (\$0.97/m^3) for mercury (D11301P p. 2).

In 1991, the vendor produced a cost estimate for the AlgaSORB technology based on bench-scale testing. Capital costs were estimated to be from \$1 to \$5/gal per day, while operating costs were expected to be from \$0.25 to \$5/gal. This figure does not include depreciation and labor. These figures were estimated based on a model system for a single metal with a capacity of 600 gal/min (864,000 gal per day). Equipment capital costs may vary from \$1 million to \$3 million for equipment only (D15904Q, p. 116).

Information Sources

D11301P, Ames Lab Homepage

D15904Q, Hazardous Materials Control Research Institute, 1991

T0659

Resources Conservation Company (RCC — Ionics)

Basic Extractive Sludge Treatment (B.E.S.T.)

Abstract

The Basic Extractive Sludge Treatment (B.E.S.T.®) process is an ex situ solvent extraction technology. The B.E.S.T. process uses one or more secondary or tertiary amines, such as diisopropylamine, to separate contaminants from soil, sediment, and sludge. This technology is applicable to most organics or oily contaminants, including polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), pesticides, herbicides, dioxins, furans, and other organic compounds.

During the B.E.S.T. process, oily sludges, soils, and sediments are separated into three phases. These phases include a water phase that can be treated by conventional treatment and discharged; a dry, treated solid phase that can be used as backfill on site; and an oil phase containing the organic contaminants. The oil phase constitutes a small volume (relative to the initial volume of contaminated material) that can be destroyed or recycled.

B.E.S.T. has several potential limitations. System performance can be influenced by the presence of detergents and emulsifiers, which can adversely affect oil/water phase separation. Because some solvents cannot exist in a liquid state in media with a pH of less than 10, performance can also be affected by alkaline feed material. Depending on the compounds present, some sludges may be reactive with the solvent under alkaline conditions. Elevated levels of volatiles can also be chemically reactive with amine solvents. In addition, some solvents used in the process, such as triethylamine (TEA), are flammable in oxygenated environments.

Technology Cost

The cost of the B.E.S.T. system varies depending on waste composition, product requirements, utility costs, flow rate, and volume. Treatment costs, excluding final disposal costs, range from \$90 to \$280 per wet ton of waste feed (D13798Y, p. 3).

A pilot-scale unit used during a demonstration of B.E.S.T. in Indiana operated at an average feed rate of approximately 90 lb of contaminated sediment per day. It is projected that the commercial unit will be capable of treating up to 186 tons of contaminated soil, sediment, or sludge per day. The treatment cost using the 186-ton-per-day (tpd) B.E.S.T. system was estimated at $112 per ton if the system is online 60% of the time. If the system is online 80% of the time, costs are estimated to be $94 per ton (D10058T, p. 15). These estimates are based on the premise that the 186-tpd system will treat greater than 5000 yd^3 of soil, sediment, or sludge containing organic contaminants. Cost estimates are representative of the charges typically assessed to the client by the vendor. All costs associated with site preparation, system mobilization, startup, and demobilization have been excluded (D10058T, p.16).

Based on pilot-scale studies at the Rocky Mountain Arsenal Superfund site near Denver, Colorado, the vendor calculated cost estimates for a full-scale B.E.S.T. unit using two separate treatment scenarios. Scenario 1 involved treating 2,840,000 yd^3 of contaminated soil over 7 years, and scenario 2 involved treating 616,900 yd^3 of contaminated soil over 2 years. The vendor estimated the cost of full-scale treatment would be $119 per ton for scenario 1 and $133 for scenario 2 (D15906S, p. 101).

In 1996, B.E.S.T. was used with Commodore Applied Technologies, Inc.'s, Solvated Electron Technology (SET) at the New Bedford Harbor Superfund Site in Massachusetts (for a description of SET refer to T0173 in the RIMS2000 library/database). The technologies were used to treat PCB-contaminated sediments, which had resulted from electronics manufacturing at the site. Based on pilot-scale results, a full-scale application of the two technologies was estimated to cost $12,971,000, or approximately $721 per ton of sediment to treat 18,000 tons. This estimate includes capital costs of $9,000,000, as well as operation and maintenance (O & M) costs of 3,971,000 (D22276E, pp. 42, 43).

The estimated total cost to treat 125,000 m^3 of soil from the Sviluppo Linate in Milan, Italy, at a rate of 25 tons per hour was $22 million. This estimate excludes excavation, debris removal, treatment and disposal of residual solids and effluents, site restoration, utilities, and the cost of bench- and pilot-scale testing (D158898, p. 333, 342). The vendor estimated that it would cost $150 to $200 per ton to treat 500,000 tons of soil using the B.E.S.T. Model 615 unit at a rate of 200 to 300 tpd. This estimate includes mobilization and demobilization costs but excludes the costs of site excavation, civil work, taxes, prescreening needs, site management, and effluent disposal (D199319, p. 6).

In 1989, B.E.S.T. was evaluated in a treatability study at the Arrowhead Refinery Superfund site in Hermantown, Minnesota. The system was used at the site to process 19,000 yd^3 of soil, 4600 yd^3 of sludge, and 13,000 yd^3 of peat. The estimated cost was $289 per ton (D12566G, pp. 455, 458, 462, 463).

Information Sources

D10058T, U.S. EPA, 1993

D12566G, U.S. EPA, 1990

D13798Y, Rodensky et al., Hazmat World, 1992

D158898, Dennis et al., 1991

D15906S, Armstead et al., 1994

D199319, Dial, 1994

D22276E, U.S. EPA, 2001

T0660

Retech, Inc.

Plasma Arc Centrifugal Treatment

Abstract

The Plasma Arc Centrifugal Treatment (PACT) is a thermal process that uses a plasma torch to treat hazardous wastes. In the presence of oxygen, the torch heats wastes to approximately

1300 to 1600°C. Organic materials are destroyed, and inorganic materials are vitrified into a leach-resistant glass. This process can treat soils, sludges, and drums of waste.

PACT systems have achieved commercial status abroad. Retech has designed on-site PACT-6 and PACT-8 units, a portable PACT-2 unit, and PACT-1 laboratory unit. This technology is commercially available.

Advantages of the PACT system include the following:

- Converts virtually all material feed into a nonleachable solid or gas suitable for discharge.
- Produces a net residue that is less than 2% of the material feed.
- Is able to process waste with high solids content.
- Processes a variety of different feedstocks (liquid, slurry, solid, drummed waste).
- Treats organics and heavy metals.
- Achieves destruction and removal efficiencies of greater than 99.99%.
- Reduces volume of waste.
- Treats heterogeneous wastes with different melting points.
- Produces less gaseous emissions than incineration.

Limitations of the PACT system include the following:

- PACT processing may not be cost effective for dilute waste liquids processing.
- Different waste streams require different feeder and off-gas treatment systems.
- Mercury is not contained within the melt and must be trapped by the off-gas system.
- Volatile metals may be only partially retained in the slag portion of the melt and may require removal by a gas scrubber or gas cleaning system.
- SITE evaluation of the PACT-6 system found it to be a high-maintenance process subject to frequent stoppage due to equipment failure.
- Plasma torches tend to require repair or replacement after less than 100 hr of use.

Technology Cost

Cost estimates were prepared for the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration in June 1992. These estimates were based on vendor information and the data gathered during the evaluation. Cost estimates were prepared for the PACT-6 pilot-scale system operating at treatment rates of 500 and 1000 lb/hr. The estimated treatment rate of the PACT-8 full-scale system was 2200 lb/hr. For each treatment rate, estimates were included for online factors of 50 and 70%. For the PACT-6 feed rate of 500 lb/hr and an online factor of 70%, the cost was estimated at $1816 per ton of material treated. For the PACT-8 feed rate of 2200 lb/hr and a 70% online factor, the projected cost was $757 per ton (D104585, p. 1).

These estimates were based on the following assumptions:

- PACT unit installed at a fixed facility
- Wastes treated equal to 2000 tons
- Operating time of 24 hr per day, 5 days per week, 50 weeks per year
- Improved feeder system, scrubber system, and a new power supply to the torch for the PACT-6 (D104585, pp. 17–20)

Items not included in this estimate:

- Permitting and regulatory costs
- Effluent treatment and disposal costs

- Analytical costs
- Site demobilization costs (D104585, pp. 18–23)

Based on costs estimated for the SITE demonstration, operation of a PACT-2 portable system was estimated to cost 30% more than a PACT fixed facility. This is an approximate estimate that assumes 2000 tons of waste require treatment and operators cost $60 per day (D104585, p. 24).

Many site-specific characteristics have an impact on vitrification technologies. One critical aspect of any thermal technology is the water content of the waste. Water dilutes feed material, requires energy to drive off, and physically limits the feed rate of waste. Feed preparation is another variable that differs with the technology and with site-specific characteristics. Some technologies can accept complete barrels of waste at a time, while others require pretreatment and size reduction. Many estimates do not take into account site preparation and waste disposal costs. Only complete treatment life-cycle assessments can provide reliable comparison data, and such studies are, by definition, highly site and waste specific (D18248T, p. 55).

Various sources estimate vitrification costs as ranging from under $100/ton to over $1000/ton for units treating hazardous waste. These estimates are assumed to be for treatment only, not including pretreatment and disposal costs. The extreme variability of the costs may be attributable to differences in feed type and water content of the waste (D18248T, p. 55).

Information Sources

D104585, U.S. EPA, 1992

D18248T, Sigmon et al., 1998

D185835, Environment Australia, 1997

T0661

Reverse Osmosis — General

Abstract

Reverse osmosis (RO) is a separation technology that uses selective semipermeable membranes to remove dissolved solids, such as metal salts, from water. In the RO process, the solution containing the contaminant(s) is applied under pressure to one side of a membrane. The water passes through the membrane, leaving behind a solution with a smaller volume and a higher concentration of solutes.

RO is widely used for desalinization of brackish water to produce a potable water source. Special membranes have been developed for industrial uses and for purifying wastewater. Metal compounds are readily removed. RO is a commercially mature technology available for many special applications including the treatment of process water from metal finishing, pulp and paper, semiconductor, and electroplating industries.

RO membranes can be fouled or damaged. This can result in low flow or holes in the membrane and passage of the concentrated solution to clean water, and thus a release to the environment. In addition, some membrane materials are susceptible to attack by oxidizing agents, such as free chlorine.

Technology Cost

Two of the major operating costs of RO plants are electrical power and membrane replacement. Table 1 summarizes the estimated costs for RO system of various sizes in 1995 dollars (D15442H, p. 20; D16192M, p. 103).

An RO system installed at a battery manufacturing plant had a capital cost of under $50,000 in 1996. Operation and maintenance cost are estimated to be $2000 per year. Cadmium chloride

TABLE 1 Estimated Costs for RO Systems of Various Sizes (1995)

Nominal Flow Rate				
Gallons per Minute	Million Gallons per Day	Capital Cost	Annual Operation & Maintenance Cost	Cost per 1000 Gal
10	0.014	$20,000	$15,100	$2.90
50	0.072	$80,000	$61,600	$2.40
100	0.144	$175,000	$112,500	$2.20
300	0.432	$450,000	$310,600	$2.00

Source: From D16192M, p. 103.

and nickel chloride as well as permeate recovered from the process are recycled. The system will pay for itself in approximately 6 months (D16278R).

Information Sources

D16192M, EPA, January 1995

D15442H, Cheremisinoff, January/February 1993

D16278R, Wisconsin Department of Natural Resources, March 1996

T0662

RGF Environmental

CO^{3}P System

Abstract
The CO^{3}P catalytic oxidation system is a complete prefabricated unit used to treat wastewater contaminated with volatile organic compounds (VOCs) and high biological oxygen demand and chemical oxygen demand. The system uses ozone, ultraviolet light, and hydrogen peroxide to create hydroxyl radicals used in oxidation.

The system is currently commercially available and has been used in multiple full-scale applications.

All information was provided by the vendor and was not independently verified.

Technology Cost
As of 1997 the RGF Environmental Systems catalog price of a CO^{3}P system is $9760.00. This system is designed for a flow rate of 30 gal/min and has a treatment capacity of up to 2000 gal. An optional 550-gal process tank is $1515.00, and a postcarbon filter is $395.00 (D17073K, p. 76).

Information Source

D17073K, RGF Environmental Equipment Catalog, 1997

T0663

Rizzo Associates, Inc.

Chlorinated Solvent Cleanup (Butane Biostimulation Technology)

Abstract
Rizzo Associates, Inc., butane biostimulation technology is a patented technology that uses butane degrading bacteria to aerobically destroy chlorinated solvents in groundwater or soil.

Microorganisms feed on the butane and in the process, co-metabolize chlorinated solvents such as trichloroethylene (TCE). The technology involves the injection of butane gas into the subsurface at a rate that allows the complete oxidation of the chlorinated contaminants.

According to the technology developers, bench-scale research has been conducted on butane biostimulation technology and a full-scale in situ pilot study has been in progress at a hazardous waste site in Massachusetts since 1997.

Researchers claim the following advantages:

- Butane-utilizing bacteria are able to tolerate higher levels of chlorinated solvents compared to those using methane or propane.
- Butane is more soluble in groundwater than methane or propane.
- Gas delivery system can operate with little or no maintenance under extreme conditions of hot and cold.
- Cost effective compared to current remediation technologies such as steam injection, bioventing, soil vapor extraction (SVE), and pump-and-treat methods.
- Can treat groundwater and adsorbed contamination.

Limitations of butane biostimulation technology include the following:

- Applicability depends on site-specific conditions such as the permeability of the subsurface and the presence and concentrations of indigenous microbes.
- Growth of butane-utilizing bacteria is controlled by the zone of butane penetration.
- Less effective in high-strength source areas.
- Lag time of approximately 1 to 2 months.

Technology Cost

According to the researchers, the cost associated with Rizzo Associates' butane biostimulation technology ranges from \$50,000 to \$75,000. This cost estimate is based on groundwater and soil cleanup over a 1- to 2-year treatment period (D19165V).

Information Source

D19165V, Parriello et al., 1998

T0664

RKK-SoilFreeze Technologies, L.L.C.

CRYOCELL

Abstract

CRYOCELL™ is a temporary barrier technology designed to contain subsurface contaminants. The system uses conventional ground-freezing technology to form a flow-impervious, removable, and fully monitored ice barrier that surrounds the contaminant source. According to the vendor, CRYOCELL can be used to contain inorganic, organic, radioactive, and biological contaminants in soil or groundwater. The technology can be applied at many site types including underground tank sites; mixed-waste sites; burial trenches, pits, and ponds; active chemical or nuclear facilities, refineries, and substations; and waste treatment lagoons. With applications dating back over 100 years, ground freezing is a well-established technology for temporary soil stabilization or groundwater control during large-scale engineering projects. The vendor states that CRYOCELL is an "off-the-shelf" technology available for immediate implementation.

Frozen barrier technologies have several potential advantages over conventional barrier technologies. Frozen barrier technologies can provide complete containment around and underneath a contaminated area. They use benign material (water/ice) as a containment medium and can be removed by thawing. In addition, frozen barriers can be easily repaired by injecting water into barrier breaches.

CRYOCELL has the following potential limitations:

- Because electrical power and utility installation are required for forming and maintaining the barrier, the technology may not be practical for remote sites.
- Applicability in arid/sandy environments is uncertain due to the absence of suitable methods for uniformly adding and retaining soil moisture.
- Applicability in fine-grained soils around buried structures (tanks, pipes, etc.) may be limited because of soil movement.
- Due to the limited use of the technology at contaminated sites, parameters such as diffusion characteristics and costs need to be further assessed.
- Limited information exists on contaminant effects on barrier performance.

Technology Cost

Several factors can influence technology costs. For example, the heat generated from high-level nuclear waste can increase expenses associated with maintaining frozen soil barriers. It is estimated that a radioactive heat source in close proximity to a barrier would increase the cost of maintenance by about $3000 per year per megacurie (D18426T, p. 1). In addition, the type of refrigerant used can influence cost (D20300P, p. 15).

High moisture content in the soil may also increase the cost of barrier installation. The vendor estimates that barrier formation in soils with 36% moisture content will cost approximately 9% more than a typical free-down period in favorable soils (16% moisture content). These elevated costs are attributed to the increase in electrical power required to freeze the additional water present in the soil (D18426T, p. 3).

According to the vendor, estimated maintenance costs for a frozen barrier located on a 10-acre site with favorable soil conditions ranges from $2000 to $4000 per month. When installation is complete, it is assumed that scheduled maintenance is required D18426T, p. 2). Table 1 gives vendor-provided installation, operation and maintenance (O & M), and removal costs on the basis of dollars per square foot of barrier face area ($/ft^2) for frozen soil barriers of various depths (D120570, p. 27).

Table 2 presents vendor-supplied cost estimates for implementing their frozen barrier technology at brownfield redevelopment sites. Costs for RKK's system are compared with costs for a sheet pile wall barrier. The estimates are based on the cost of containment at a 3.5-acre site with contamination 50 ft below ground surface (D221647, p. 3).

TABLE 1 Frozen Soil Barrier Costs from RKK, Ltd.

	Barrier Depth (ft)				
Cost Category	150	125	100	75	40
Installation/barrier formation,[a] $/ft^2	$11.87	$12.30	$12.84	$13.53	$14.41
Annual O & M,[b] $/ft^2/year	$0.78	$0.79	$0.80	$0.82	$0.84
Removal,[c] $/ft^2	$1.78	$1.78	$1.78	$1.78	$1.78

Source: Adapted from D120570, p. 27.

[a]Includes 2 years of power @ $0.065/kWh and operations; $ per square foot of barrier face area.

[b]After 2 years; includes power @ $0.065/kWh.

[c]Includes well closure and recovered materials decontamination, destruction, or beneficial reuse.

TABLE 2 Vendor-Supplied Cost Estimates for Using Frozen Barriers and Sheet Pile Wall Barriers at Brownfield Redevelopment Sites (Assumes a 3.5-Acre Site with Contamination 50 Ft Deep)

Technology Components	Sheet Pile Wall Barrier (millions of dollars)	Frozen Soil Barrier (millions of dollars)
Barrier installation	\$2.0–\$2.5	\$1.2–\$1.6
Barrier operation (20 years)	—	\$0.2–\$0.4
Pile foundation costs	\$1.0–\$2.0	\$1.0–\$2.0
Total costs	\$3.0–\$4.5	\$2.4–\$4.0

Source: Adapted from D221647, p. 3.

Table 3 gives costs assembled during the U.S. Department of Energy (DOE) full-scale demonstration at the SEG site in Oak Ridge, Tennessee. The total capital cost for the 5-month demonstration was \$481,427. DOE estimated that by deducting demonstration costs (such as extra sensors and test support), purchasing rather than renting equipment, and decreasing the barrier thickness, the cost at an actual site would be \$332,754. Cost estimates were based on a 5- to 15-ft-thick barrier with an area of approximately 1100 ft^2 and a volume of 8200 ft^3 of soil. Costs were reported per cubic foot of barrier volume. For comparison, DOE provided typical grout emplacement costs of \$1/ ft^3 to \$37/ ft^3, depending on grout formulation (D11254Z, p. 9). The estimated percentage contributions for each component of the frozen soil barrier system are shown in Table 4 (D120581, p. 45).

At the end of the Oak Ridge demonstration, energy consumption had dropped to 1100 kWh/day, or \$2145 per month at \$0.065/kWh. The refrigeration units were operated on a "fix-when-fail" basis during the demonstration. Equipment failures accounted for roughly \$1600 during the demonstration, or \$400 per month. The long-term cost of the ground freezing demonstration was estimated at \$2545 per month (D120581, p. 47). However, system maintenance alone cost about \$3322 per month at the site according to a U.S. Environmental Protection Agency (EPA) source (D20300P, p. 17).

A CRYOCELL system was proposed for use at the Hanford U.S. DOE facility in the State

TABLE 3 Frozen Soil Barrier Cost Estimates Based on Oak Ridge Demonstration Barrier[a]

	By Operational Time Line				
	5.5 months	Year 1 Total	Years 2–5	Years 6–10	Years 11–15
Demo site, \$/ft^3 (total cost: \$481,427)	\$13	\$14	\$4	\$6	\$6
Actual Site, \$/ft^3 (total cost: \$332,754)	\$9	\$10	\$4	\$6	\$6

	15-Year Maintenance Costs	
	Average Maintenance Costs	Maintenance Costs per Month
Demo site, \$/ft^3	\$1.20	\$0.09
Actual site, \$/ft^3	\$1.12	\$0.09

Source: Adapted from D11254Z, p. 9.

[a] 5- to 15-ft-thick barrier containing a 1100 ft^2 area and 8200 ft^3 of soil.

TABLE 4 Frozen Soil Barrier Component Costs[a]

Cost Component	Percent Total Cost
Design/engineering	4
Drilling	37
Underground materials	12
Manifolds, valves, connectors, insulation	6
Freeze (refrigeration) plants	14
Electrical power	10
Labor	13
Support	4

Source: Adapted from D120581, p. 45.
[a] Oak Ridge demonstration barrier.

of Washington to contain strontium-90 and tritium contamination. Phase I of the project would involve installing a CRYOCELL system at the edge of the contaminant plume. Costs for this phase are projected to be \$7 to \$10 million for barrier installation and \$2 to \$3 million for operational costs over 10 years. Phase II of the project, which would involve "full enclosure" of the contaminant source, is projected to cost from \$10 to \$14 million (D20825D, pp. 3–5).

Information Sources

D120570, RKK, Ltd., 1996b (Statement of Qualifications)
D11254Z, U.S. DOE, 1995
D120581, SEG, 1995 (Volume 1)
D18426T, RKK-SoilFreeze Technologies, LLC, web page, 1998
D20300P, U.S. EPA, 1999
D20825D, RKK-SoilFreeze Technologies, LLC, undated
D221647, RKK-SoilFreeze Technologies, LLC, undated

T0665

RKK-SoilFreeze Technologies, L.L.C.

CRYOSWEEP

Abstract

RKK, Ltd., is researching an in situ freeze separation technology called CRYOSWEEP™, a patented process that separates concentrated water-soluble contaminants from groundwater. The vendor claims CRYOSWEEP can be used to remove radioactive, organic, and ionic solutes. The technology lowers the temperature of soil, creating a freezing front of contaminant-rich water that can be steered to collection systems. The technology has currently undergone only bench-scale testing.

The vendor states that the advantages to CRYOSWEEP include:

- Technology operates in situ.
- Technology is site specific and can be engineered to operate under structures without risk of damage.
- Remediation can be scaled for removal projects of various sizes.

- Technology may be more cost effective than pump-and-treat methods.

Technology Cost

According to theoretical performance data supplied by the vendor in 1995, if cooling panels 40 m wide and 3 m high are placed 5 m apart, 7640 kWh are required to freeze the soil between the panels. At \$0.06/kWh, this works out to a unit cost of \$0.77/m^3. Total energy cost of freezing that volume of contaminated soil is \$459. This estimate assumes an initial soil temperature of 32°F (0°C). Higher initial soil temperatures would require more energy to freeze (D12030P, pp. 7–8).

Information Source

D12030P, U.S. Patent, 1995

T0666

RKK-SoilFreeze Technologies, L.L.C.

ISOCELL

Abstract

The commercially available, patented technology known as ISOCELL™ is an in situ process designed to immobilize hazardous, radioactive, and mixed waste for safe retrieval, storage, transportation, and treatment. The ISOCELL technology stabilizes, isolates, and contains waste during mobilization and prevents any mixing of buried waste during waste recovery. The ISOCELL technology freezes soil into blocks so that the hazardous waste can be safely removed from the ground and transported for holding purposes or for later volume reduction of the waste.

According to the vendor, the ISOCELL technology can provide in a frustum-shaped block of preselected size the complete isolation and removal of radioactive materials from in situ site conditions. The technology uses lifting and/or glazing to keep wastes contained inside the frozen blocks and to reduce dust and aerosol releases during lifting and mobilization processes.

The technology can be applied to:

- Removal and mobilization of exploded and unexploded ordnance (including fired shells containing nerve gas or other harmful chemicals)
- Removal of mixed waste from burial trenches
- Removal of sludge and sediment from treatment/settling ponds
- Removal of radioactive waste
- Removal of smaller underground storage tanks, transfer sumps, or equipment
- Rusting drums or gas cylinders
- Spill sites

The vendor asserts that the advantages of the ISOCELL technology include:

- Protection for health and safety of workers, and the environment
- Notable reductions in costs, especially at mixed-waste sites
- Minimization of exposure to airborne contaminants, and reduced mixing of wastes during recovery processes
- Soil-influencing equipment installed by a driving process, eliminating site drilling, and minimizing atmospheric releases by dust or aerosol

- Block sized to match the requirements of the mitigation process and transportation specifications

The major limitations to the technology are thawing of frozen waste blocks and the possibility of rupturing a waste container during equipment installation.

Technology Cost
The cost for the ISOCELL technology varies depending on site variables such as site size, wastes to be treated at the site, waste treatment method, transportation costs, disposal costs, and other general factors that may affect the costs. An appropriate cost for using the ISOCELL technology can only be determined on a site-by-site basis, considering all factors that affect cost (personal communication: Ronald K. Krieg, RKK, Ltd., December 1996).

T0667

RMT, Inc.

Metals Treatment Technology (MTT)

Abstract
The Metals Treatment Technology™ (MTT™) is a chemical fixation process that stabilizes heavy metals in soils, sludges, and sediments. The process uses buffered phosphate compounds to convert heavy metals into insoluble metallic salts. The process chemicals may be applied to contaminated media in situ or ex situ.

MTT is commercially available in several forms. Enviro-Blend® is used as a remediation technology to treat contaminated soils, sludges, and sediment. This mixture also serves as a pollution prevention technology to treat industrial waste streams. Enviro-Blend is distributed exclusively by American Minerals, Inc. The Enviro-Prep System® stabilizes the lead in paint and is commercially available through Hoffer's Coatings, Inc. Enviro-Prep Special is another MTT product that is used to stabilize lead contamination in utility access points.

According to the developer, MTT technologies have several advantages:

- Use lower doses of chemicals than traditional treatments such as lime or Portland cement.
- Have a lower bulking factor, reducing handling and disposal costs.
- Use standard soil mixing equipment.
- Stabilize metals, allowing final product to be placed in nonhazardous landfills.

MTT reduces the leachability of heavy metals, but it does not reduce the concentrations of total metals present. Zinc concentrations greater than 10% impair the ability of the process to effectively treat cadmium and may result in high dosages of required treatment chemicals.

Technology Cost
According to the vendor, treatment costs using MTT generally range from \$20 to \$70 per ton (D103662, p. 39). In 1999, the vendor estimated the treatment costs for using Enviro-Blend to treat mercury-contaminated soil. These costs ranged from \$80 to \$100 per ton (D22760L, pp. 13, 14). Table 1 summarizes site-specific cost data provided by the vendor.

Table 2 displays a cost estimate prepared for the U.S. Army Environmental Center (USAEC). This estimate assumed that the Enviro-Blend compound cost \$340 per ton and was applied at a ratio of 3% by weight. Disposal costs of \$14 per ton were used (D22759S, p. 14).

Factors that have a significant impact on treatment costs include (in descending order of importance):

TABLE 1 Vendor Estimated Costs for Full-Scale Metal Treatment Technology Applications

Site	Contaminant	Media	Amount Treated	Unit Cost
C & R Battery Superfund Site, Richmond, Virginia	Lead	Soil	38,000 tons	\$90 per ton
Confidential Iron Melting Site	Lead	Sludge	350,000 yd^3	\$25/yd^3
Orchard, Door County, Wisconsin	Lead, arsenic	Soil	5,000 yd^3	\$60 per ton
Fox River Bridge, near Menasha, Wisconsin	Lead	River sediment	500 tons	\$80 per ton

Source: Adapted from D103662.

TABLE 2 Cost Estimate Prepared for the U.S. Army Environmental Center

Cost Item	Cost per Ton
Materials	\$10
Equipment and labor	\$1
Disposal	\$14.40
Total cost	\$25.40

Source: Adapted from D22759S.

- Initial contaminant concentrations
- Disposal cost of nonhazardous residues
- Quantity of waste
- Characteristics of the residual waste
- Site preparation
- Labor rates
- Target contaminant concentrations
- Amount of debris with waste
- Waste handling/processing costs (D103662, p. 39)

MTT was used to treat 3500 yd^3 of lead-contaminated soil at a scrap yard in Wisconsin Rapids, Wisconsin. The project included landfilling the treated soil and an additional 3500 yd^3 of other material, a treatability demonstration, implementation of the remedial action, closure sampling, and preparation and submittal of a documentation report. According to the vendor, the total project costs were approximately \$210,000 or \$30/yd^3 of soil treated (D13684P, p. 3).

At a former battery recycling site in Wisconsin, the technology was used to stabilize 55,000 yd^3 of soil contaminated with lead. The total treatment costs were \$50 per ton of soil treated, in 1994 dollars. This figure includes remediation costs, analytical costs, and consulting fees. The chemicals used during the demonstration cost approximately \$12 per treated ton of soil. It is estimated that disposal in a hazardous landfill would have cost more than \$200 per ton (D14485O, p. 1227).

Information Sources

D103662, VISITT 5.0, 1995
D13684P, RMT, Inc., 1994
D14485O, Chowdhury et al., 1994

T0668

Rochem Environmental, Inc.

Disc Tube

Abstract
The Disc Tube™ system is a patented, ex situ process for the treatment of aqueous solutions ranging from seawater to leachate. The system uses high-pressure reverse osmosis through a semipermeable membrane to separate pure water from contaminated liquids.

In 1998, Rochem Group licensed the technology to Pall Corporation (Pall). Prior to 1998, the license for the U.S. Disc Tube market was held by Rochem Environmental, Inc. According to the vendor, the technology has been used successfully in more than 900 European and U.S. petroleum-related applications. Between 1989 and 1995, Disc Tube systems were used to treat landfill leachate at over 30 European landfills.

According to the vendor, the Disc Tube technology has the following advantages:

- Has a greater tolerance for dissolved solids and turbidity than other membranes.
- Exhibits a long membrane life.
- Is easy to maintain as all membranes are readily accessible.
- Operates with minimal supervision.
- Exhibits greater resistance to membrane scaling and fouling than other technologies.
- Has larger flow channels and achieves higher flow velocities than other membrane separation systems.
- Is compact and flexible.

The performance and membrane life of a Disc Tube system may be limited by the composition of the influent waste stream. The maximum water recovery rate is dependent on the total dissolved solids (TDS) concentrations in the influent waste. The efficiency of the Disc Tube technology is also affected by temperature.

Technology Cost
Typical operating costs of the Disc Tube system in 1995 dollars are summarized in Table 1. Capital costs are approximately $444,000 (in 1995 dollars) for a standard 20-module unit capable of treating from 60 to 80 gallons per minute (gpm). Treatment costs tend to decrease with increasing treatment capacity. In general, treatment costs are higher for Disc Tube systems used to remediate liquid wastes with high scaling potentials (D12813C, p. 1.5; D23022Y, pp. 2, 12).

As part of the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration program, the Disc Tube was used to treat leachate from the Central Landfill Superfund site in Johnston, Rhode Island. The EPA used the data from this demonstration to estimate the costs for a Disc Tube system that treats 3 gpm and a system that operates at 21 gpm. Both theoretical systems were fixed facilities that treated leachate similar

TABLE 1 Typical Operating Costs of the Rochem Disc Tube (1995)

Operation and Maintenance Cost	Unit Cost ($/1000 gal)
Labor	4.60
Maintenance	0.70
Spare parts	0.70
Energy cost	1.10
Chemical cost	2.70
Membrane cost	4.40
Labor for membrane replacement	0.20
Total	14.40

Source: Adapted from D12813C, p. 1.5.

to the leachate from the Central Landfill, operated at a 90% online efficiency factor of 90%, and recovered 75% of the permeate. The 3-gpm system cost $0.16/gal or permeate treated. The treatment costs for the 21-gpm Disc Tube system were $0.06/gal of permeate generated. Annualized equipment and consumables cost accounted for almost half of the total treatment costs. These estimates did not include the costs of permitting or concentrate disposal because these elements are site and leachate specific (D23022Y, p. 11; D20806A, pp. 18–22). Table 2 displays a breakdown of the EPA's cost estimates.

According to the vendor, the Disc Tube module systems in Europe treated leachate flows ranging from 10,000 to 500,000 gallons per day (gpd). The average cost was less than 4 cents per gallon in 1994 (D13060Z, p. 58).

Pall Corporation owns and operates a Disc Tube system at the BFI Conestoga Landfill in Morgantown, Pennsylvania. According to Pall, the treatment costs to the landfill's owner are less than $0.08/gal of leachate treated (D23021X, pp. 43–45).

Information Sources

D12813C, The Hazardous Waste Consultant, 1995

TABLE 2 Estimated Costs for the Treatment of Leachate Using Disc Tube Technology

Cost Factor	Cost per Gallon of Permeate Using a 3-gpm System ($)	Cost per Gallon of Permeate Using a 21-gpm System ($)
Site facility preparation	0.001	0.0001
Annualized equipment	0.041	0.019
Startup and fixed costs	0.030	0.012
Labor	0.034	0.005
Supplies	0.006	0.002
Consumables	0.032	0.014
Residuals and waste shipping, handling, and transport	0.006	0.002
Facility modifications, repair, and replacement	0.005	0.001
Total	0.16	0.06

Source: Adapted from D20806A.

D13060Z, GWMR, 1994
D20806A, U.S. EPA, 1998
D23021X, Pall Corporation, undated
D23022Y, U.S. EPA, 1998

T0669

Rocky Mountain Remediation Services, L.L.C

Envirobond and Envirobric

Abstract
Envirobond™ is a stabilization technology that may be applied in situ or ex situ to treat solids (soils, sediments, wastes, and sludge) contaminated with heavy metals and radionuclides. Envirobond's proprietary blend of chemical additives combine with heavy metals and radionuclides to form an insoluble, stable mass. The Envirobric™ volume reduction system compacts the stabilized solids into construction-grade bricks.

Envirobond and Envirobric have been used at full-scale, field deployments. Envirobond and Envirobric are no longer commercially available. BNFL, Inc., and Washington Group International now own the rights to these technologies.

According to the vendor, Envirobond and Envirobric technologies have the following advantages:

- Allows for on-site treatment and disposal of soils contaminated with heavy metals.
- Requires a smaller volume of treatment chemicals than most stabilization technologies.
- Produces bricks with high compressive strength and low porosity.
- Permanently binds metals in a leach-resistant solid.
- Reduces costs by avoiding excavation, transportation, and off-site disposal charges.

The Envirobond chemical binder is less effective in media containing more than 30% by weight of aluminum, magnesium, calcium, and manganese. The metals preferentially bind with the Envirobond mixture and reduce the number of chelating sites available for other metals.

Technology Costs
According to the vendor, total costs for an ex situ Envirobond application average between \$10 and \$30 per ton. The vendor indicates that the average costs of in situ Envirobond applications range from \$5 to \$25 per ton. in situ applications are generally more cost effective because they avoid transportation and disposal costs. The cost per ton is impacted by the type of waste and the amount of wastes that require treatment (D20479F, p. 1; D204819, p. 5).

In Stockton, Utah, Envirobond was used to treat 13,900 tons of mill and smelter waste contaminated with lead, cadmium, and arsenic. The total cost of the in situ application was \$200,000 (D204808, p. 6). Based on these data, the total cost of the remediation is approximately \$14 per ton.

The total cost to treat 2000 tons of mine waste contaminated with lead, zinc, arsenic, and mercury at a historic gold mine in Central City, Colorado, was \$55,000. According to the vendor, Envirobond was applied ex situ at a total cost of approximately \$20 per ton (D204808, p. 8; D20477D, p. 2; D20479F, p. 1).

At a battery recycling site in Portland, Oregon, Envirobond was applied ex situ to remediate 13,000 tons of lead-contaminated soil. The total cost of the project was \$200,000 (D204808, p. 10). Based on these data, the total cost of this project was estimated at \$15 per ton.

Rocky Mountain Remediation Services, L.L.C. (RMRS) was awarded a \$16 million contract to use the Envirobond and Envirobric technologies to treat 5100 yd^3 of uranium production residues at the U.S. Department of Energy's (DOE's) Fernald facility in Fernald, Ohio. RMRS was contracted to design and construct a remediation facility, retrieve and treat the residues, package the treated waste, and shut down and dismantle the remediation facility (D20477D, p. 1; D204808, p. 2). Under a $1.7 million contract with the DOE, RMRS used Envirobond to treat 80,000 gal of pond sludge contaminated with cadmium at the DOE Rock Flats Facility near Denver, Colorado (D204808, p. 3).

Information Sources

D20476C, Hasbach, undated
D20477D, RMRS, undated
D20479F, RMRS, undated
D204808, RMRS, undated
D204819, RMRS, undated

T0670

Rohm and Haas Company

Amberlite XAD-4

Abstract

Rohm and Haas Company has developed Amberlite® polymeric adsorbent resins that can be used to remove organic compounds from contaminated groundwater, aqueous wastes, and vapor-phase wastes. Amberlite XAD-4 is a crosslinked polystyrene-type polymer. It is hydrophobic and has no ionic functional groups incorporated into its resin structure. The material is most useful in removing low-molecular-weight organic substances from aqueous systems. Amberlite XAD-4 has been commercially available since the 1970s.

The vendor states that Amberlite XAD-4 has the following advantages:

- Allows for recovery of contaminants in a reusable form.
- Uses steam to regenerate the resin, minimizing disposal and material costs.
- Offers flexibility, as the technology can be used as a stand-alone system or as part of a treatment train.

According to the vendor, Amberlite XAD-4 has an upper temperature limit of 480°F and requires a minimum resin bed depth of 30 inches when used to treat liquid-phase contaminants. Nitric acid and other strong oxidizing agents can cause explosive reactions when mixed with ion exchange resins. Other oxidants, such as oxygen, chloride, peroxides, or ozone may destroy the activity of ion exchange resins. Difficulties in treating waste streams contaminated with humic materials have been reported. Like all adsorbents, Amberlite may physically degrade by abrasion or osmotic forces. This attrition is undesirable since it leads to pressure drops and to loss of material from the system.

Technology Cost

According to information supplied by the vendor in 1997, a minimum order of 400 ft^3 of Amberlite resin would cost $530/$ft^3$ (personal communication: Barbara Kinch, Rohm and Haas Company, January, 1997).

Based on a pilot-scale system regenerable system used to remove ethylene dichloride from contaminated groundwater at a site near Lake Charles, Louisiana, a cost estimate was prepared for a full-scale system. The estimated costs were compared to a variety of conventional treatment alternatives, including air stripping and vacuum steam stripping. The Amberlite XAD-4 resin system with regeneration had a projected operating cost of less than $0.01/gal of water treated. The system provided a savings of greater than 90% over those projected for operating an air stripper. On an annual basis, and at projected flow rates, operating costs savings were estimated to be over $7000 per day, greater than $2.5 million per year (D169384, p. 64).

Information Source

D169384, Bonn and Tornatore, 1997

T0671

Rohm and Haas

Ambersorb 563

Abstract

Ambersorb 563 is a carbonaceous adsorbent for remediating groundwater and air emissions contaminated with volatile organic contaminants (VOCs), including chlorinated organics. Ambersorb adsorbents are hard black plastic beads made from ion exchange resins that are partially pyrolized under controlled conditions. Ambersorb is used in pump-and-treat remediation techniques and has been demonstrated in a pilot-scale project through the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation Program (SITE). This technology is commercially available.

According to the vendor, advantages of Ambersorb 563 include the following:

- Beads are not prone to bacterial fouling and have extremely low ash levels.
- Estimated capacity is 5 to 10 times greater than granular activated carbon (GAC) for low concentrations of VOCs.
- Systems tend to be more compact than GAC units because they operate at higher flow rate loadings.
- Adsorbent can be regenerated on-site using steam stripping, thus eliminating the liability and cost of off-site regeneration or disposal.
- Condensed contaminants are recovered through phase separation.
- May offer a cost-effective alternative to sir stripping and GAC.

Limitations of Ambersorb 563 include the following:

- Initial capital costs are greater than for GAC; however, operation and maintenance costs are lower.
- Long-term durability of the beads is unknown.
- Reductions in adsorption capacity after the first steam regeneration.

Technology Cost

Initial costs for Ambersorb 563 are higher than for GAC, however, savings may be realized after the system has been operating for approximately 18 months when the impact of lower operation and maintenance costs are felt. Cost information from a U.S. EPA SITE program demonstration in 1994 at the former Pease Air Force Base in Newington, New Hampshire, is presented in Table 1. The actual demonstration was pilot scale, with a rate of 1 gal/min (4 liters/min), but the cost data is based on a 100-gal/min (389 liters/min) extrapolation from the pilot study.

TABLE 1 Cost for a 100-Gal (389-liters)/min Ambersorb Treatment System[a]

Cost Category	5 Years	10 Years	15 Years	20 Years
Installed costs	$526,100	$526,100	$526,100	$526,100
Operating costs	$104,391	$178,820	$231,887	$269,724
Maintenance costs	$75,854	$129,936	$168,496	$195,989
Replacement costs	$0	$7,005	$12,000	$15,561
Salvage value	($17,825)	($10,167)	($5,437)	($2,584)
Total present worth	$688,520	$831,695	$933,047	$1,004,789

[a]Estimate based on discount rate of 7.0%.

Information Source

D10513V, EPA SITE Emerging Technology Summary, 1995

T0672

Rohm and Haas Company

Ambersorb 600

Abstract
Ambersorb 600 is a carbonaceous adsorbent for removal of low levels of volatile organic compounds (VOCs) from vapor streams. The adsorbents are placed in a fluidized-bed adsorption system that can attain a high flow rate. Ambersorb 600 is a commercially available technology.

The system includes an adsorption stage to collect and concentrate the VOCs using Ambersorb 600 and a separate desorption stage that minimizes the thermal energy necessary to recover the concentrated VOCs. The desorbed contaminants are then either condensed or destroyed by oxidative techniques.

Advantages of Ambersorb 600, according to the vendor, include:

- Significant capacity advantage for low contaminant concentrations, especially under humid conditions
- Insensitive to fluctuating influent concentrations
- Fast desorption kinetics
- Regenerable
- Excellent physical stability
- Low water adsorption at high relative humidity
- Less prone to cause bed fires

Technology Costs
Ambersorb 600 is sold by the dry pound. Shipping weight is 33 lb (15 kg) per cubic foot, and a minimum order is 4 lb (1.8 kg). It can be purchased in full 55-gal (208-liter) drums (220 lb) or in 1-lb (0.45-kg) containers. The price per pound, when purchased as a full drum, is $35.00, or in 1-lb containers the price is $60.00/lb.

Information Source

D127128, vendor literature

T0673

Rotating Biological Contactors — General

Abstract
Rotating biological contactors (RBCs) are used to facilitate the ex situ treatment of aqueous waste streams by aerobic bioremediation. A typical RBC involves a polymer foam-coated horizontal cylinder that is partially submerged in the waste solution. As the cylinder is rotated along its horizontal axis, the surface is alternately plunged into the waste and withdrawn, forming a film coating of the waste solution. The resulting film improves aeration that facilitates aerobic bioremediation. RBCs are widely used for bioremediation of organic and nitrogenous compounds. RBCs may also be used for anaerobic bioremediation by submerging the unit completely and covering the facility to prevent air from entering.

RBCs are susceptible to many of the same constraints as any biological treatment. They are not effective at removing most inorganics or nonbiodegradable organics. Wastes containing high concentrations of heavy metals, certain pesticides, herbicides, or highly chlorinated organics may inhibit microbial activity and limit performance.

RBCs were first developed in Europe in the 1950s but were not used commercially in the United States until the late 1960s. Since that time, RBCs have become fairly common for the treatment of high volume municipal and industrial wastewaters. These systems are currently in use throughout the country and are commercially available from a number of vendors.

Technology Cost
According to one estimate by the U.S. Environmental Protection Agency (EPA), a single RBC unit will cost from $80,000 to $85,000 to purchase and install. This estimate was for an RBC with a surface area between 100,000 and 150,000 ft^2 (D15372K, p. 7).

At the Homestake Mine in Lead, South Dakota, 48 RBCs were installed to treat 5.5 million gallons of discharge water per day. The system degraded thiocyanate, free cyanide, and metal-complexed cyanides, and also removed ammonia, which is a by-product of cyanide degradation. Over time, as the system became more efficient, the cost to treat cyanide dropped from $11.79 to $3.10/kg (D15372K, p. 6).

Information Source

D15372K, U.S. EPA, 1992

T0674

Roy F. Weston, Inc.

Low-Temperature Thermal Treatment (LT3)

Abstract
The low-temperature thermal treatment (LT3) uses thermal desorption to volatilize organic compounds under noncombustion conditions. The contaminants are evaporated from excavated soil

by means of an indirect heat exchanger that heats and dries contaminated soils (D12576I, p. 41). The system uses a hollow-screw auger for mixing, moving, and indirectly heating the contaminated soil. LT3 is applicable to a variety of soils with a wide range of moisture and contaminant concentrations. The system is best suited for treating volatile organic compounds (VOCs) in relatively dry soil.

The technology is patented and commercially available.

According to the vendor, the LT3 system has several advantages:

- Has a lower cost than incinerators or comparable thermal technologies.
- Is smaller in size than incineration systems.
- Uses indirect heating methods to remove contaminants.
- Recovers the organic contaminants.
- Operates at a low temperature to minimize the volatilization of heavy metals.

The vendor claims that the LT3 technology is best suited for soils with a moisture content of less than 20% and VOC concentrations up to 1%. Semivolatile organic compounds (SVOCs) with boiling points over 500°F can also be treated, but treatment may impact processing costs. Soils with a moisture content between 20 and 50% require dewatering prior to treatment and must be treated at a reduced rate. Pretreatment screening or crushing of soil aggregate larger than 2 inches may also be required.

Technology Cost

The vendor estimated that treatment costs using LT3 would range from $60 to $150 per ton of material treated. The cost of the technology will vary based on the moisture content of the soil, other soil characteristics, amount of debris in the waste, and the characteristics of the residual waste (D22730F, pp. 4, 5).

The U.S. Navy performed a field demonstration of the LT3 system. The unit treatment cost based on this demonstration averaged $268 per ton. This figure excluded the costs associated with permitting, excavation, progress reports, soil and stack sampling, and oversight. The Navy stated that the costs would be lower if larger volumes of soil were treated (D20878Q, p. 32).

After a demonstration at the U.S. Department of Defense's (DOD's) Tinker Air Force Base in Oklahoma, additional cost estimates were prepared for the LT3 process. The estimated unit cost for processing and decontaminating soil with similar contaminants a rate of 8 tons per hour was $86 per ton. The total estimated costs for treating 5000 tons were $116 per ton. The fixed costs for mobilization, startup, and demobilization were estimated to be approximately $150,000 (D12576I, p. 42).

The U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration program tested the LT3 technology at the Anderson Development Company Superfund site in Adrian Michigan. The EPA prepared a economic analysis based on the moisture content of the soil. Wet soils and sludges will require dewatering prior to treatment, a longer treatment time, and more energy to heat, dry, and treat the soil. During the demonstration, treatment costs were also affected by the volume and type of waste, treatment goals, regulatory requirements, site accessibility, and characteristics of the residual waste. Operating costs were most affected by the rate of feed and the residence time of the thermal processor (D104610, pp. 1, 2; D107528, p. 163). The details of the EPA's cost estimates are presented in Table 1.

Information Sources

D104610, U.S. EPA, 1992

D107528, U.S. EPA, 1995

D12576I, U.S. EPA, 1991

TABLE 1 Cost Analysis of the Low-Temperature Thermal Treatment (LT3) System for a 3000-Ton Project

Cost Categories	Cost per Ton of Soil Containing 20% Moisture ($)	Cost per Ton of Soil Containing 45% Moisture ($)	Cost per Ton of Soil Containing 75% Moisture ($)
Administrative costs	11.00	11.00	11.00
Fencing costs	0.40	0.40	0.40
Construction costs	0.70	0.70	0.70
Dewatering costs	NA[a]	NA	187.90
Permit	3.30	3.30	3.30
Engineering support	80.00	80.00	80.00
LT3 rental	13.00	22.00	22.00
Support equipment rental	1.90	3.65	3.65
Optional equipment rental	12.00	20.00	20.00
Mobilization	10.00	10.00	10.00
Assembly	25.00	25.00	25.00
Shakedown	15.00	15.00	15.00
Operations staff	39.00	79.50	79.50
Site manager	21.60	44.30	44.30
Maintenance supervisor	7.20	14.60	14.60
Site safety officer	7.20	14.60	14.60
Personal protection equipment (PPE)	6.00	10.00	10.00
Disposal drums	1.70	2.20	2.20
Activated carbon	8.00	24.00	24.00
Diesel fuel	0.65	1.00	1.00
Calibration gasses	0.35	1.10	1.10
Natural gas	7.80	26.00	26.00
Electricity	2.10	6.30	6.30
Water	0.60	0.60	0.60
Residual waste transportation	39.60	46.80	46.80
Treatability study and sample analysis	14.20	22.00	22.00
Maintenance	11.70	19.80	19.80
Site demobilization	33.00	33.00	33.00
Total cost	373.00	536.85	724.75

Source: Adapted from D104610.
[a]NA, not applicable.

D20878Q, Heath et al., 2000
D22730F, U.S. EPA Reachit, undated

T0675

Roy F. Weston, Inc.

Transportable Incineration Systems

Abstract
Transportable incineration systems (TISs) are rotary kiln incinerators used for the ex situ treatment of soils, sludges, sediments, liquids, and debris contaminated with heavy metals, polychlorinated biphenyls (PCBs), and other hazardous organic substances.

Roy F. Weston, Inc., owns and operates two TISs: the TIS-5, capable of treating 7 tons per hour (tph) of waste, and the TIS-20, designed to treat up to 30 tph. Both employ a two-stage combustion process for incineration of hazardous waste. Transportable incineration is generally cost-effective for sites containing more than 1000 tons of contaminated media.

Although TISs may volatilize heavy-metal contaminants, the metals are not broken down or destroyed, and ash that contains excessive levels of heavy metals must be stabilized to meet toxicity characteristic leaching procedure (TCLP) prior to being disposed of in a landfill.

Technology Cost

According to the vendor, the fixed costs of TISs ranged from $1 million to $3 million per site in 1994. Fixed costs are associated with site preparation, regulatory requirements, mobilization, setup, and demobilization (D130723, pp. 223–224).

In 1994, a TIS unit was used to remediate PCBs at the Coal Creek Superfund Site in Chehalis, Washington. Approximately 33,000 tons of soils were excavated, and highly contaminated soils were separated from soils with minimum contamination. Approximately 9700 tons were treated with the TIS-5; the remaining soil was stabilized and backfilled into an in-site containment cell (D115377). The actual cost for remediation at the site was approximately $8,100,000, or approximately $830 per ton. The extensive excavation and material handling at the site added to the total remediation cost (D184672, p. 77).

A TIS-20 was used to remediate soils at the Savanna Army Depot Activity site in Savanna, Illinois. Approximately 75,900 tons of soil were processed. Unit costs were estimated at $173/ton (D21498M).

Actual costs for treatment with a TIS were given by the vendor in 1994 as ranging from $150 to $250 per ton of waste treated. These costs are dependent on contaminant levels, chemical characteristics, media treated, safety considerations, and moisture content (D130723, p. 224).

Information Sources

D130723, Johnson, Remediation/Spring 1994

D115377, Young & McPhillips, May 1995

D184672, U.S. EPA, 1998

D21498M, Los Alamos National Laboratory, undated web page

T0676

Rusmar Inc.

Long-Duration Foam

Abstract

Rusmar Inc. offers a family of long-duration foam products. These products are used for odor suppression, control of volatile organic compound (VOC) and semivolatile organic compound (SVOC) emissions, dust control, and promotion of surface water runoff. The vendor has provided information for several full-scale commercial applications of long-duration foam technology. The technology is commercially available currently.

The vendor states that long-duration foams can be used during many remediation activities. These include trenching, mucking sludge lagoons, bucket excavating, draining lagoons, staging for incineration, mixing pit waste preparation, and covering dormant areas.

The vendor claims the following advantages of AC-900 Series Long-Duration Foam:

- Is a noncombustible, nonhazardous material that can be used on irregular and vertical surfaces.

- Controls odors and prevents landfill material from attracting scavengers and other disease vectors.
- Promotes surface runoff by sealing materials, reducing leachate formation.
- Controls emission of volatile compounds and dusting.

The weather may limit the applicability of Long-Duration Foam AC-645. The foam will not withstand a heavy downpour and should not be used on days when rain is in the forecast.

Technology Cost
In 1990, the engineering manager for the Delaware Solid Waste Authority stated that the monthly costs associated with the use of long-duration foam were $6200 for the lease of the spraying machine and approximately $7500 for the foam. The manager also stated that although the cost of the foam and application machinery was slightly higher than the cost of applying a soil cover, the overall cost was reduced due to labor and space savings (D220600, p. 8).

Information Source

D220600, Finegan, 1990

T0677

Rust Federal Services, Inc.

VAC*TRAX Thermal Desorption

Abstract
VAC*TRAX is an ex situ thermal desorption process that separates contaminants such as volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), polychlorinated biphenyls (PCBs), and radioactive materials from soils, sludges, and solid trash. This process can be applied to mixed and unmixed waste streams. Because the nitrogen atmosphere in which the process occurs is inert, no combustion of organic material takes place.

This system is still in the demonstration stage. Treatability studies have been conducted at several vendor facilities on bench- and pilot-scale systems. A demonstration of the technology on actual mixed low-level waste (MLLW) was conducted in fiscal year 1995 on the VAC*TRAX demonstration unit. According to information from the vendor received in September 1999, the company is closed for business and VAC*TRAX is no longer available.

VAC*TRAX is different from other thermal desorption processes in that it is a vacuum dryer. By sealing the drying chamber and reducing the air pressure, a vacuum is created. The vacuum allows a much lower temperature to be used in the dryer, enabling the use of smaller, more transportable equipment.

VAC*TRAX is a mobile system that uses existing process equipment and requires minimal custom-fabricated process equipment. This system is also flexible enough to perform over a range of variations of the processing parameters (e.g., concentration of contaminants). VAC*TRAX is suitable for sites with small soil volumes (200 to 2000 m^3).

VAC*TRAX heats contaminated waste to the point at which the contaminants separate from the solids. To prevent combustible waste from burning, nitrogen, which is nonflammable, is introduced into the dryer, replacing the oxygen and other flammable gases. Heat is applied for 1 or 2 hr, and then the vacuum is applied. The length of time the vacuum is applied depends on the type and amount of waste being treated.

As the waste is heated, the contaminants are vaporized. The nitrogen forces the gases through a filtered outlet, safely trapping any solid particles such as dust within the dryer chamber. The gas then passes through a series of condensers that cool the gas in three stages. The condensed

liquid is trapped, collected, and removed for off-site disposal. The solids left in the dryer are virtually free of organic contaminants. The vacuum is released, a sealed door in the bottom of the dryer is opened, and the solid waste is dropped into a container under the dryer.

Technology Cost
No available information.

T0678

S.G. Frantz Company, Inc.

Magnetic Barrier Separation

Abstract
S.G. Frantz Company, Inc., is the manufacturer of magnetic barrier separation devices that remove heavy metals and radionuclides from contaminated soils, sludges, and radioactive wastes. The technology uses magnetic fields to separate particles with differing magnetic properties. Magnetic barrier separation has been evaluated for remediation purposes in pilot-scale testing and the equipment is commercially available.

According to the vendor, the magnetic barrier laboratory separator has a significant advantage over isodynamic separators (the magnetic intensity is constant throughout the applied field) in the nature of the applied field. The magnetic energy gradient in the barrier field has a pattern resembling a packet of thin sheets, with the surfaces of the sheets aligned with the lengthwise axis of the gap between the pole pieces of the magnet. Isodynamic magnetic fields are applied across the surface of each sheet. Across the width of the separating region, there is a magnetic gradient with low values at the outer fringes of the field, and a maximum value near the center of the separating region. If the particle has a susceptibility that attracts it to the applied field, it is deflected toward the field. Particles with opposite susceptibilities are deflected away from the field. Other advantages of the magnetic barrier laboratory separator are that material is visible as it enters the magnetic field and undergoes separation at the magnetic barrier. This allows for better control, superior sensitivity, and greatly reduced processing time.

According to the vendor, only particles from about 2 mm to 50 μm in size can be processed by magnetic barrier separation. Some bench-scale studies suggest that high feed rates decrease separation efficiency. Materials undergoing magnetic barrier separation must then be processed by some treatment technology before the hazardous component of the waste can be disposed.

Technology Cost
In 1995, the vendor estimated the cost of processing wastes using magnetic barrier technology ranged from \$60 to \$6,000 per ton. Among factors cited by the vendor as effecting costs were, in decreasing order of importance, quantity of waste, target contaminant concentration, waste handling and preprocessing needs, site preparation, characteristics of soil, amount of debris associated with the waste, characteristics of the residual waste, initial contaminant concentration, moisture content of soil, depth of contamination, depth to groundwater, utility and fuel rates, and labor rates (D103786, p. 38).

Magnetic susceptibility is the ratio of the magnetization of a substance to the applied magnetization force. The vendor states that magnetic susceptibility differences between the contaminants and the residue affects the concentration that can be obtained, as well as the time required for treatment. The greater the difference in the magnetic susceptibility of the target contaminant and the residue, the more efficiently the contaminants can be extracted (D103786, p. 38).

Superconducting magnetic equipment will be required for any full-scale treatment of large quantities of waste. These systems have been used for industrial applications, but not for remediation purposes. Until such remediation systems are designed, built, and used, performance and cost cannot be evaluated (D103786, p. 38).

Information Source

D103786, VISITT 4.0, 1995

T0679

S.M.W. Seiko, Inc.

Soil–Cement Mixing Wall

Abstract
The soil–cement mixing wall (SMW) is an in situ technology for the fixation, stabilization, and solidification of soils contaminated with metals and semivolatile organic compounds. SMW can be used to treat soils contaminated with pesticides, polychlorinated biphenyls (PCBs), phenols, and polyaromatic hydrocarbons (PAHs) to depths of up to 100 ft. The technology uses hollow-stem augers to inject solidification/stabilization agents and blend them with the soil.

RIMS was unable to contact the vendor. It is not known if the technology is currently commercially available.

Technology Cost
No available information.

T0680

S.S. Papadopulos & Associates, Inc.

Detergent Extraction of Non-Aqueous-Phase Liquids in the Subsurface (DeNAPLs)

Abstract
Detergent extraction of non-aqueous-phase liquids in the subsurface (DeNAPLs) is a self-contained technology for the removal and treatment of non-aqueous-phase organic compounds. The DeNAPLs process involves in situ surfactant-enhanced groundwater flushing, followed by ex situ groundwater treatment. According to the vendor, the technology may be used for the treatment of dense non-aqueous-phase liquid (DNAPL) and light non-aqueous-phase liquid (LNAPL) compounds in groundwater, soil, and sediment. The technology is also suitable for other types of geologic media such as porous media and fractured bedrock, if the downward migration of the non-aqueous-phase liquid (NAPL) can be controlled during in situ surfactant flushing. DeNAPLs is commercially available through S.S. Papadopulos & Associates, Inc.

For aquifers with sufficient permeability and controlled NAPL migration, extraction using DeNAPLs can be accomplished in months. The DeNAPLs process can also increase the solubility of NAPLs by one or more orders of magnitude, depending on the chemical or mixture of chemicals in question.

The DeNAPLs technology may not be effective at sites with the following characteristics:

- An aquifer with a permeability of less than 0.001 cm/sec
- A contaminant zone with a thickness of more than 50 ft
- A complex mixture of contaminants

According to a report published by the U.S. Environmental Protection Agency (EPA), DeNAPLs may not be appropriate for the treatment of polychlorinated biphenyls (PCBs) in freshwater sediments.

Technology Cost
At a pipeline compressor station in Delmont, Pennsylvania, the cost of using DeNAPLs was approximately \$100/ft^2. This project involved the removal of PCBs from fractured rock at the site. According to the vendor, total project costs were \$500,000 (personal contact: Jim Lolcama, S.S. Papadopulos & Associates, Inc.).

A report published by the U.S. EPA indicated that the DeNAPLs process costs \$11/ft^2 for treatment in bedrock (D22982X, p. 16). Another U.S. EPA source listed a cost range of \$30 to \$50/ft^2 of aquifer. This estimate includes preprocessing costs but excludes the costs associated with excavation, permitting, and disposal of residues (D22926P, p. 6).

The following factors can affect the cost of treatment using DeNAPLs:

- Soil characteristics
- Depth of contamination
- Waste quantity
- Target contamination concentration
- Depth to groundwater
- Site preparation (D103775, p. 18).

Information Sources

D103775, VISITT 4.0, 1995
D22926P, U.S. EPA, undated
D22982X, U.S. EPA, 2000

T0681

Safety-Kleen Corporation

PPM Dechlorination Process

Abstract
The mobile PPM process treats polychlorinated biphenyl- (PCB-) contaminated oil at ambient temperatures and pressures and results in a clean, recyclable oil, according to the vendor. PPM Canada, Inc., a wholly owned subsidiary of USPCI, was founded in 1983 to provide PCB destruction methods. According to the vendor, while the process has been used extensively for PCB-contaminated oil, the process is still in development for soils and is not commercially available. Safety-Kleen Corporation has since bought out USPCI. The process was developed for Union Pacific Railroads. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0682

Sandia National Laboratories

In Situ Electrokinetic Extraction (ISEE)

Abstract
In situ electrokinetic extraction (ISEE) is an in situ extraction technology that uses specialized lysimeter electrodes to remove anionic contamination from unsaturated soil. This technology is primarily used on soils with low permeabilities. During ISEE, a direct electric current is

passed between two electrodes causing the ionic contaminant to concentrate near the anodes. The targeted species can then be removed from the soil without excavation by electroplating techniques, pumping, precipitation, or ion exchange resins.

The technology has undergone bench-scale testing and a field demonstration in conjunction with the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration program. ISEE is not commercially available.

Sandia National Laboratory (SNL) claims the following advantages to ISEE:

- Cleanup can be targeted to a specific area since treatment only occurs between electrodes.
- Has relatively low energy demands due to the low current requirements.
- Removes metals from low-permeability, unsaturated soils.
- Does not significantly affect soil makeup.
- Is one of the few in situ heavy-metal remediation technologies.

ISEE is limited by the type of contaminant, pH, pore water chemistry, amount of pore water, contaminant and noncontaminant ion concentrations, precipitation reactions, and reduction–oxidation properties of the site. It may be difficult to estimate the time that will be required to remediate a site using this technology. Heterogeneities or anomalies in the soil will reduce removal efficiencies. ISEE is a developing technology. Further research is required to determine the technology's limitations and ramifications.

Technology Cost

In 1996, the developer estimated that treatment costs using ISEE would range between $50 to $150 per ton. Comparable processes involving excavation can cost from $200 to $500 per ton (D13192A, p. 111). The ceramic electrodes used in the research prototype cost $15,000 for each electrode assembly (D123819, p. 5; D22756P, p. 2).

According to the Interstate Technology and Regulatory Cooperation (ITRC) Work Group, the costs of electrokinetic remediation applications will vary based on the site's specific chemical and hydraulic properties. The initial and target contaminant concentrations, concentrations of nontarget ions, conductivity of the pore water and soil, soil characteristics and moisture content, the quantity of waste, depth of contamination, residual waste handling and processing, site preparation requirements, and electricity and labor rates have a significant effect on the unit price. The U.S. Army Environmental Center states that equipment, installation, maintenance, removal, and contaminant disposal costs can significantly increase the costs of using electrokinetic remediation for turnkey operations (D19938G, pp. 16, 17; D10137R, p. 24; D21596N, p. 9; D22781Q, p. 66).

In 1996, the ISEE system was used to remove 200 g of hexavalent chromium from 16 yd^3 of soil at the U.S. Department of Energy's (DOE's) Unlined Chromic Acid Pit located at the Sandia National Laboratory's (SNL's) Chemical Waste Landfill in Albuquerque, New Mexico. The treatment costs for this 4-week demonstration were $1368/$yd^3$. According to the U.S. EPA, these costs were calculated for the ISEE prototype used during the demonstration. The costs for a full-scale system would be lower due to design improvements and efficiency of scale (D22781Q, pp. 65, 66; D22758R, pp. 44–51).

Information Sources

D10137R, VISITT 4.0, undated

D123819, Webtech, undated

D13192A, U.S. DOE, 1996

D19938G, ITRC, 1997

D21596N, U.S. Army Environmental Center, 2000

D22756P, U.S. DOE, undated

D22758R, U.S. EPA, 1998

D22781Q, U.S. EPA, 2000

T0683

Sandia National Laboratories and Illinois Institute of Technology Research Institute

Thermal-Enhanced Vapor Extraction System (TEVES)

Abstract

The thermal-enhanced vapor extraction system (TEVES) is an in situ technology designed to remove and treat organic chemicals from contaminated soils. The technology is based on the idea that added heat increases the mobility of semivolatile and volatile organic compounds (SVOCs and VOCs) and thus facilitates the extraction of soil contaminants. Thermal-enhanced vapor extraction combines a vacuum extraction system with two soil heating methods: resistive heating, which uses powerline frequency energy, and dielectric heating, which uses radio frequency energy. One row of electrodes generates heat and two exterior rows of electrodes contain the heat within the treatment zone. Two dual-purpose vacuum extraction wells and an off-gas treatment system then remove and treat the heated soil contaminants.

TEVES has been used to treat soils contaminated with laboratory-generated organic wastes including alcohols, aldehydes, amines, ketones, benzene and substituted benzenes, ethers, phenols, polymers, and heterocyclic compounds. The largest volume of organic wastes treated were volatile organic compounds (VOCs) and various types of oils (hydraulic, transformer, heat transfer fluid, and motor oils).

Applications are highly dependent upon the specific soil and chemical properties of the contaminated media. Normally, feasibility studies are required before installing such a system. Also, system performance is contingent upon the length of treatment time and the final temperature of the soil.

This technology is able to remove soil contaminants without the need to excavate, retrieve, and perform ex situ treatment. Electrical heating can be used to heat soil and remove contaminants hundreds of feet underground. Also, heating soil improves subsurface conditions for biodegradation of residual contaminants.

Technology Cost

In the fall of 1994, the TEVES was demonstrated at the Sandia National Laboratories Chemical Waste Landfill (CWL) as part of the Department of Energy's Mixed Waste Landfill Integrated Demonstration Program (D12881O, p. 1325).

The CWL demonstration required 85,000 kW of energy at a cost of \$7000. Implementation costs for the TEVES configuration were approximately \$150/yd^3 of soil. Testing of the TEVES system was due to be completed in 1995, at which time a cost analysis for commercial applications was to be submitted as part of the final demonstration report (D15517J, p. 2; D131395, p. 27; D15518K, p. 5).

Information Sources

D12881O, Phelan et al., date unknown

D15517J, Sandia National Laboratories, date unknown

D131395, Subsurface Contaminants Focus Area, 1996

T0684

Sanexen Environmental Services, Inc.

Biolysis

Abstract

The Biolysis™ process is an aerobic bioremediation treatment designed to treat soils and sludges with a high solids content contaminated with petroleum hydrocarbons and nonsoluble organics. It can be applied as a continuous operation in reactors or in situ in settling lagoons. The technology has been applied full scale and is commercially available.

The process consists of three basic steps: pretreatment, a high rate biotransformation of hydrocarbons, and digestion. The pretreatment step is required to liquefy and equalize the feed stream. When soils are fed, the large grain size fraction can be transferred to a vessel where the material is washed. The overflow is directed to the second reactor where the biodegradation takes place. The biodegradation is a highly exothermic process that evaporates off water, thus reducing the volume of the waste, and allowing the treatment to take place in cold winter months. Digestion is a biological polishing step, followed by moving the treated wastes into a drying bed.

The technology is not designed for metals.

Technology Costs
At a site in Quebec, Canada, the technology met project economic objectives with cost of remediation totaling $75 per metric ton of treated material. The total cost for the project was $200,700. Costs are in Canadian dollars (D14835Q, p. 1).

Information Source

D14835Q, The National Contaminated Sites Remediation Program (Canada)

T0685

Sanexen Environmental Services, Inc.

Decontaksolv

Abstract
Decontaksolv™ is a mobile autoclave/solvent extraction system for decommissioning polychlorinated biphenyl (PCB) contaminated equipment. Decontaksolv was developed and commercialized by Sanexen Environmental Services, Inc., in Canada in the 1980s. From 1985 to 1994 it was used to decontaminate 3 million kilograms of PCB-contaminated equipment.

The Decontaksolv system uses extraction fluids to desorb and solubilize the PCB components from wall surfaces and the core and windings of equipment. The efficiency of decontamination is a function of the induced pattern of phase change of the extraction fluid within the material containing the PCBs, a different pattern being used for each type of equipment. The decontamination mode used depends on the type of equipment, transformers, capacitors, or other material being processed, and on the size of the equipment and concentration of PCBs.

The primary limitation of the Decontaksolv system is that it only removes the PCBs; it does not destroy them.

According to the vendor, Decontaksolv offers the following advantages:

- Allows recovery and recycling of steel, copper, and aluminum.
- Reduces PCB inventories and overall storage costs.
- Reduces time needed for mandatory inspections.
- Easily mobilized on owners site.
- Eliminates the need and cost of storage and of eventual transportation for destruction.

Technology Costs
According to the vendor, Sanexen sells decontamination services rather than equipment. The price depends on the quantity and type of material to be treated. The technology costs less than incineration (D14782U, p. 3).

Information Source

D14782U, vendor literature

T0686

Sanexen Environmental Services, Inc.

Ultrasorption

Abstract

Ultrasorption™ is a water treatment process for extraction of both organic and inorganic contaminants. It has been used in multiple actions and is commercially available as either a modular, transportable unit, or a fixed installation.

Ultrasorption is based on the different affinities of contaminants for water and a selected solvating agent. The substances, adhering to a solid media that maximizes the contact surface area, are capable of strongly partitioning contaminants from the water phase. The substance used acts both as a dissolution fluid where the contaminants become trapped, and a de-emulsifier that reduces the affinity of the contaminants for the water.

The media is claimed to be longer lasting and more cost effective than granular activated carbon (GAC). GAC is often used downstream of Ultrasorption as a polishing step. In this configuration, the GAC will last longer than if it is used without Ultrasorption.

Technology Costs

According to the vendor, capital costs of an Ultrasorption system is about 60% of an equivalent GAC system. Operational costs and disposal of the treatment media are approximately half of those associated with GAC units. Manpower requirements are the same in both cases (D14750M, p. 11).

Information Source

D14750M, Sanexen, vendor literature

T0687

Sanitaire Corporation and ABJ Group

Intermittent Cycle Extended Aeration System (ICEAS)

Abstract

Sanitaire Corporation and ABJ Group developed the ex situ wastewater treatment system known as the intermittent cycle extended aeration system (ICEAS™). ABJ describes the ICEAS system as a variation of a sequential batch reactor (SBR) system that operates on the principle of continuous feed (inflow) with intermittent cycles of aeration, settling, and effluent decantation. This means that the influent flow is received continuously within a single basin, even during settling and decant phases of the operational cycle.

According to the developer, more than 300 of the patented ICEAS systems are in operation in applications such as treatment of municipal wastewater and high-strength industrial waste from chemical plants, tanneries, and food processing plants.

According to ABJ, the ICEAS technology's ability to operate using the principle of continuous feed (inflow) with intermittent cycles of aeration, settling, and effluent decantation, distinguishes it from other SBR systems. ABJ claims that this feature makes it unnecessary to

bypass a tank during settling and decanting, thereby enabling the system to adapt to shock and peak loads during processing.

Technology Cost
No available information.

T0688

Savannah River Ecology Laboratory

Selective Colloid Mobilization

Abstract
The selective colloid mobilization technology helps suspend microscopic particles and their attached contaminants so they can be easily removed from groundwater. According to the developer, environmentally benign chemical compounds are used to selectively mobilize tiny, contaminant-carrying particles called colloids. The mobilizing agents selectively mobilize the iron oxide and hydroxide fractions and thus segregate the minerals to which the contaminants adhere. The technology suspends the colloids, and the colloids with their attached contaminants can be pumped with the groundwater to the surface for above-ground treatment. Once the water is at the surface treatment facility, a pH adjustment is performed to promote flocculation and settling of the colloids, which are removed before the water is returned to the aquifer. The process can be repeated until the water meets the cleanup standards. The developers are currently building a pilot-scale unit and a patent is pending.

The physical and chemical characteristics of the aquifer will significantly influence the success of this technology. The technology works best with metal and organic contaminants but also will work with dense, non-aqueous-phase liquids and petroleum hydrocarbons. Because the technology relies on advective flow, it works best on moderately to highly permeable aquifers. It also works best in soils having low organic carbon and high oxides content (a minimum of 5 to 10% of the clay mineral fraction).

Advantages of this technology include:

- In situ technologies are typically less disruptive and expensive than ex situ technologies.
- Selective dispersion reduces the potential for formation plugging.
- Selective colloid mobilization enhances removal of strongly sorbed contaminants, increasing remediation efficiency.
- Leaching the treatment solution in highly weathered formations maintains a depressed solution pH and inhibits additional partitioning of solution-phase metals to the solid phase.

Technology Cost
Preliminary information indicates that the annual cost of selective colloid mobilization may be comparable to pump and treat, but that the cleanup would be faster, which would decrease cleanup costs (D14840N, p. 183). It is estimated that using the technology at one groundwater remediation project at the Department of Energy's Savannah River site will reduce cleanup costs by several million dollars and cut the cleanup time in half (D14839U, p. 8).

Information Sources

D14840N, Ground Water Monitor, 1996
D14839U, Inside R&D, 1996

T0689

SBP Technologies, Inc.

Membrane Filtration

Abstract

The SBP membrane filtration system concentrates contaminants and reduces the volume of contaminated groundwater, surface water, storm water, landfill leachates, and industrial process water. This hyperfiltration system consists of stainless steel tubes coated with a multilayered membrane, which is formed in-place using proprietary chemicals. The membrane filtration system can be used with an SBP bioremediation system or another technology as part of a treatment train.

SBP Technologies, Inc., is no longer in business. Although the membrane filtration system has been field demonstrated, the technology is not commercially available.

The SBP hyperfiltration system has several unique features that provide advantages over conventional membrane processes in wastewater treatment applications. SBP uses a proprietary formed-in-place membrane technology. The properties of the membrane can be varied by controlling the types of membrane chemicals used, their thickness, and the number of layers. The formed-in-place membrane can be quickly and economically reformulated in the field to accommodate changes in waste characteristics or treatment requirements. SBP uses a cross-flow filtration mechanism to continuously clean the surface of the membrane, minimizing fouling. The formed-in-place membrane is compatible with a wide range of chemical cleaning methods. If the membrane should become irreversibly fouled, it can be stripped and reformulated on site.

The membrane filtration technology is suitable for treating waters with chemical oxygen demand (COD) levels ranging from 100 to 500 mg/liter. The technology is most efficient at concentrating contaminants with molecular weights greater than 200.

Technology Costs

The total annual operating costs for a 12-module filtration unit range between $514,180 and $1,209,700. The operating costs vary depending the flow rate through the unit, the cleanup requirements, and the cost of effluent treatment and disposal. Effluent treatment and disposal costs, if considered, could account for up to 60% of the total cost. Labor can account for up to 40% of total annual costs. Processing costs depend more on labor costs than on equipment costs. The unit cost of the technology can be broken down by flow rate. Table 1 displays the estimated cost per 1000 gal and 1000 liters by flow rate (D10055Q, pp. 20–21).

Table 2 summarizes the costs associated with remediating a hypothetical site. The economic analysis is extrapolated from a cost estimate prepared during a U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration of

TABLE 1 Cost of Filtration Treatment at Various Flow Rates with or without Effluent Treatment

	Flow Rate in Gal/Min (Liters/Min)		
	24 gal/min (91 liters/min)	12 gal/min (45 liters/min)	7.2 gal/min (27 liters/min)
With effluent treatment, $/1000 gal	$288–$522	$456–$1044	$760–$1739
With effluent treatment, $/1000 liter	$76–$138	$120–$276	$201–$459
Without effluent treatment, $/1000 gal	$222	$444	$739
Without effluent treatment, $/1000 liter	$59	$117	$195

Source: From D10055Q.

TABLE 2 Hypothetical Site Cost Analysis, 10-Year Project (1993 Dollars)

Site preparation	$85,000
Permitting and regulatory	$15,000
Equipment	$900,000
Startup	$5,000
Labor	$1,990,800
Consumables and supplies	$35,000
Utilities	$106,000
Effluent treatment and disposal	$1,669,248
Residuals	$460,000
Analytical	$600,000
Facility modification, repair, and replacement	$371,500
Demobilization	$10,000
Total	$6,247,548

Source: From D10055Q, p. 28.

the technology. The hypothetical site contains groundwater contaminated with wood-preserving wastes [creosote and pentachlorophenol (PCP)]. The remedial plan calls for containment of the groundwater plume and eventual aquifer restoration. The model assumes that approximately 2 million gallons of water are contaminated and that 10 pore volumes of groundwater (20 million gallons) must be treated to restore the aquifer. The concentrate from the process will be treated on-site by bioremediation at a cost of 40 cents per gallon. The remedial time frame is 10 years (D10055Q, p. 26).

Information Source

D10055Q, U.S. EPA, 1993

T0690

SBP Technologies, Inc.

Slurry-Phase Bioremediation

Abstract
The SBP slurry-phase bioremediation system can treat a wide range of organic contamination, especially wood-preserving wastes and solvents. A modified version can also treat polynuclear aromatic hydrocarbons (PAHs) such as creosote and coal tar; pentachlorophenol (PCP); total petroleum hydrocarbons (TPH); and chlorinated aliphatics, such as trichloroethene (TCE). The technology can be combined with SBP's membrane filtration system to form a soil cleaning system to handle residuals and contaminated liquids.

SPB Technologies, Inc., is no longer in business. The slurry-phase bioremediation technology has been used in field demonstrations but is no longer commercially available.

When used with physical extraction and separation techniques as part of a treatment train, slurry-phase bioremediation has the following advantages:

- Various types of media, including surface water, groundwater, soil, and sediment, can all be treated at the same time.

- Various types of contaminants, including organic, inorganic, and radioactive wastes, can be treated at the same time.
- Contaminants can be separated into fractions, thus making biodegradation more efficient.
- Slurry-phase bioremediation is more efficient than conventional biological technologies when treating high-molecular-weight PAHs.
- Treatment systems can be entirely mobile.

Slurry-phase bioremediation is not effective for treating metals and other inorganic contaminants. This limitation may be overcome by using slurry-phase bioremediation with a physical separation technology, such as soil washing or filtration. Temperature, pH, nutrient status, oxygen potential, and contaminant bioavailability can also be limiting factors in the slurry-phase bioremediation process.

Technology Costs
Soil characteristics, initial contaminant concentrations, and target cleanup levels all have significant impacts on the cost of slurry-phase bioremediation. In 1993, the cost of treatment was estimated to be \$100 to \$150/m^3 of waste treated (D10336W, p. 33). For groundwater contaminated with 100 to 2000 parts per million (ppm) of PAHs, SBP estimated treatment costs to range from \$0.10 to \$0.40/gal (D10055Q, p. 25).

Weber et al. (1999) researched the costs of various technologies suited for treating soils contaminated with heavy polycyclic aromatic hydrocarbons (hPAHs). Cost information was collected for slurry-phase biological treatment and for the following technologies: intermittently mixed batch reactors; landfarming; composting; composting with mechanical mixing; excavation, retrieval, and off-site disposal; soil flushing; solidification/stabilization; vitrification; biopile; chemical extraction; chemical oxidation/reduction; thermal desorption; and pyrolysis. This information, which was attained from various federal sources, indicated that slurry-phase biological treatment was one of the least expensive methods (D194723, pp. 79, 80).

Weber et al. reported that high-end costs for slurry-phase biological treatment were just under \$200/yd^3 of soil treated. This value represented the lowest of the high-end values reported. Weber et al. noted that these high-end values are more realistic representations of hPAHs treatment costs since these compounds are highly hydrophobic. Hydrophobic compounds have slower treatment rates and thus require longer treatment times. This factor adds to remediation costs (D194723, pp. 79, 80).

Information Sources

D10336W, U.S. EPA, 1993

D10055Q, U.S. EPA, August 1993

D194723, Weber et al., 1999

T0691

SBP Technologies, Inc.

Solid-Phase Bioremediation

Abstract
Solid-phase bioremediation is an ex situ treatment technology for soil and sediment contaminated with total petroleum hydrocarbons (TPH), polynuclear aromatic hydrocarbons (PAHs), and phenols, including pentachlorophenol (PCP).

The contaminated soil is processed through a specially designed machine that shreds the soil and adds compost material. Nutrients, water, and specialized microorganisms may be added to achieve the proper moisture level and inorganic nutrient level for optimum bioremediation. The soil can then be transferred to a bioreactor or made into a biopile and placed in covered structures or covered with a liner.

SBP Technologies, Inc., has closed for business. The solid-phase bioremediation technology has been used during full-scale remedial applications but is not longer commercially available.

According to the vendor, the solid-phase bioremediation technology has several advantages:

- Is less costly that landfilling or thermal desorption.
- Produces a clean, rich soil suitable for reuse as backfill.
- Can treat contaminants on-site.

According to the vendor, the technology is most effective on soils contaminated with TPH or low-molecular-weight PAHs. Based on specific site characteristics, volatile emissions may need to be controlled during excavation and treatment.

Technology Cost

In 1995, the vendor estimated that SBP solid-phase bioremediation costs between $40 and $75 per ton of soil treated. Initial and target contaminant concentrations, soil characteristics, and the moisture content of the soil greatly influence treatment costs (D10335V, p. 36; D225025, p. 15).

According to the vendor, the cost to remediate 7000 yd^3 of soil contaminated with total petroleum hydrocarbons (TPH) at a service station in South Carolina was less than \$45/yd^3. At a wood preserving site in New Jersey, remediation activities cost a total of $1,300,000 or an average of \$50/yd^3 (D10335V, p. 10, 20).

Information Sources

D10335V, VISITT, July 1995

D225025, U.S. EPA Reachit, undated

T0692

SCC Environmental

Micro-Flo

Abstract

The Micro-Flo™ is a mobile wastewater treatment system that uses physical and chemical treatments to remove both organic and inorganic contaminants from wastewater, surface water, and groundwater. The Micro-Flo uses a combination of processes that may include the addition of oxidizing or reducing agents, flocculation, coagulation, pH adjustment, particle settling, microfiltration, ultrafiltration, and adsorption. The technology is self-contained on a transportable 45-ft trailer and can be assembled in one day.

Micro-Flo has been used at many sites throughout Canada to treat wastewater and surface water contaminated with polychlorinated biphenyls (PCBs), chlorophenols, polycyclic aromatic hydrocarbons (PAHs), phenols, dioxins, furans, hydrocarbons, metals, oil, and grease. The technology has also been used to treat water contaminated with paint, paint thinner, and paint solvents.

The Micro-Flo has been tested by Environment Canada under the Development and Demonstration of Site Remediation Technologies (DESRT) Program. It is commercially available from SCC Environmental, of Newfoundland and Nova Scotia, Canada.

According to the vendor, Micro-Flo has several advantages:

- Treats water contaminated with PCBs, pentachlorophenol (PCP), PAHs, phenols, metals, oil, grease, dioxins, and furans at a low cost.
- Is a fully automated, mobile treatment system.
- Requires minimal manpower.

Technology Cost
No available information.

T0693

SCC Environmental

Thermal-Phase Separation Unit

Abstract
SCC Environmental has developed the transportable thermal-phase separation (TPS) unit. The TPS unit is an indirectly heated thermal desorption system that treats soil and sludge contaminated with chlorinated hydrocarbons and polycyclic aromatic hydrocarbons (PAHs). The vendor states that the technology has been applied successfully to several contaminated sites on a full-scale basis and is commercially available.

The TPS system is a thermal desorption device. In thermal desorption, heat is used to volatilize organic contaminants. This separates the contaminants from the contaminated media. The technology allows for a significant reduction in the amount of material requiring subsequent treatment or disposal.

SCC Environmental claims the following advantages of the TPS system:

- Achieves high removal efficiency of polychlorinated biphenyls (PCBs), PAHs, and pentachlorophenol (PCP).
- Has substantially lower remediation costs than incineration.
- Emits off-gases similar to those of an industrial boiler.
- Has high process throughputs.
- Allows for volume reductions of up to 99%.
- Has a versatile, mobile, modular design.
- Is more easily permitted than incineration and more acceptable to the public.

The TPS system is capable of treating contaminated soil or sludge with organic concentrations of less than 30%. Contaminants to be treated must have boiling points of less than 600°C. Particle size of the treated media must be less than 0.75 inches in diameter.

Technology Cost
SCC Environmental is the owner and operator of the TPS unit. The vendor contracts out the unit for soil and sludge decontamination projects. In 1997, Enviro Access stated that costs of TPS technology generally ranged from $250 to $350 (Canadian) per metric ton of contaminated waste treated. This figure included the disposal fee for the concentrated liquid contaminant extracted during processing. Costs are dependent on the quantity of waste to be treated, the type of contaminant present, the moisture content of the material, and the size and plasticity of the media treated (D17891A, p. 4).

Information Source

D17891A, Enviro Access, 1997, web page

T0694

Schonberg Radiation Corporation

Toxic Remediation Using Radiation

Abstract
Schonberg Radiation Corporation has been assigned a patent for a transportable treatment system that uses a diverging beam electron gun to treat vapor-phase volatile organic compounds (VOCs) that have been extracted from the ground using an existing technology such as soil vapor extraction.

RIMS was unable to contact the developer of this technology. The current state of, and the commercial availability of this technology are therefore unknown.

Technology Cost
There is no available information regarding the costs associated with this technology.

T0695

Science & Engineering Associates, Inc.

Barometrically Enhanced Remediation Technology (BERT)

Abstract
The Barometrically Enhanced Remediation Technology (BERT™) removes and recovers volatile organic contaminants from soil by enhancing the natural air exchange that occurs in soil as a response to changes in atmospheric pressure. This process is sometimes referred to as barometric pumping or passive soil vapor extraction. The process is a low-cost complement to conventional active-extraction methods because investment and maintenance costs are low and no power is needed. The passive process is better suited than conventional methods for certain problems.

The primary application of the BERT technology will likely be to complement active soil vapor extraction efforts by removing residual contaminants after active methods become insufficient. It could also be used on the edge of unsaturated zone contaminant plumes where concentrations of volatile contaminants are low or for enhancement of bioremediation activities. The primary advantages of the technology application are low capital costs and minimal operating costs. The system is well suited for applications in low-risk contaminant settings, where rapid response and remediation are not necessary. Suitable applications include volatile contaminants at relatively shallow depths (less than 20 ft) in the vadose zone, such as:

- Surface spills of fuels and solvents
- Leaking buried pipes or pipe galleries
- Underground storage tank leaks
- Shallow buried waste
- Residual, shallow volatiles remaining after the baseline treatment is finished
- Asphalt or cement covers over contaminated sites
- Landfill covers

BERT has been field tested and the developer states that it is ready for commercial implementation.

Technology Cost

According to the developer, installation costs are low because no excavation or drilling is required, and no secondary waste is generated. Operating costs are minimal because the system requires no site power and the components need relatively zero maintenance (D192921, p. 3).

At the Idaho National Engineering and Environmental Laboratory (INEEL), the basic system installation cost was about $3.47/ft^2, for a total cost of about $34,700. This figure does not include site characterization and monitoring costs (D192921, p. 10).

Information Source

D192921, Lowry et al., 1999

T0696

Science Applications International Corporation

Plasma Hearth Process

Abstract

Science Applications International Corporation (SAIC) is developing the plasma hearth process (PHP) for the treatment of hazardous, radioactive, and mixed waste. The technology is being researched with the support of the U.S. Department of Energy (DOE). PHP is a high-temperature thermal treatment that uses a direct current (DC) plasma arc torch to destroy organic compounds and melt inorganic materials into a leach-resistant, glassy slag. The term *plasma* is used to describe a highly ionized electrically conductive gas. The plasma torch operates in a transferred arc mode, meaning that the torch uses a flow of gas (usually nitrogen) to stabilize the electrical discharge between a high-voltage electrode inside the torch and a molten pool of waste that is kept at ground potential. Due to the high resistance of electrical current flow through a gas, electrical energy is converted to heat. Plasma gas temperatures can reach 10,000°C. PHP technology has been researched with bench- and pilot-scale units.

SAIC states that the technology is commercially available and lists the following advantages of PHP technology:

- Processes a wide variety of containerized wastes.
- Requires no pretreatment of wastes or additives.
- Produces a stable, leach-resistant, vitrified final waste form.
- Destroys organic compounds.

If wastes with high melting points are treated, it may be necessary to add flux material prior to treatment. This will affect processing costs. The PHP is not designed for treating gaseous wastes. PHP is not economical for treating large volumes of low-heating-value liquid waste (e.g., wastewater).

Technology Cost

In 1993, the vendor estimated procurement and construction costs of a full-scale (1000 kg/hr) PHP system for the treatment of mixed and hazardous wastes would be approximately $2 million. The largest development costs are associated with U. S. Environmental Protection Agency (EPA) quality trial burn testing and radioactive demonstration testing. Permitting costs are expected to be similar to that required for an incinerator system (D12887U, pp. 5–6).

In 1998, the projected costs for a full-scale PHP facility designed to process 17,000 m^3 of waste over 5 years were $124 to $184 million. Capital costs were estimated to range from $50 million to $86.2 million for facility construction and outfitting. The startup operating cost was projected to range from $12 to $62 million. Over the 5-year operating period, the estimated cost of operations and maintenance were $48 million to $62 million. The expenses for a one-year decontamination and decommissioning period ranged from $4 million to $8 million. Researchers estimated that product disposal costs would be approximately $10 million. The projected unit cost ranged from $7400 to $10,800 per cubic meter of waste treated (D19601U, p. 24; D210491, p. 185).

Most of the cost data for vitrification technologies are estimates based on pilot-scale operations. Such data are suspect because they are based more on extrapolation than on experience. Such estimates are difficult to compare because the assumptions on which they are based may vary widely (D18248T, p. 55).

Many site-specific characteristics have an impact on vitrification technologies. One critical aspect of any thermal technology is the water content of the waste. Water dilutes feed material, requires energy to drive off, and physically limits the feed rate of waste. Feed preparation is another variable, which differs with the technology and with site-specific characteristics. Some technologies can accept complete barrels of waste at a time, while others require pretreatment and size reduction. Many estimates do not take into account site preparation and waste disposal costs. Only complete treatment life-cycle assessments can provide reliable comparison data, and such studies are, by definition, highly site and waste specific (D18248T, p. 55).

Various sources estimate vitrification costs as ranging from under $100/ton to over $1000/ton for units treating hazardous waste. These estimates are assumed to be for treatment only, not including pretreatment and disposal costs. The extreme variability of the costs may be attributable to differences in feed type and water content of the waste (D18248T, p. 55).

Information Sources

D12887U, AMESLAB, 1993

D18248T, Sigmon and Skorska, 1998

D19601U, U.S. DOE, 1998

D210491, Federal Remediation Technologies Roundtable, 2000

T0697

Science Remediation Services

Electro-Migration

Abstract

Electro-migration is an in situ bioremediation technology that utilizes a direct electrical charge to deliver microorganisms through a remediation site. The technology remediates heavy asphalts and crudes in tight clays and saturated sands. According to the vendor, the technology is ideal for areas under buildings, roads, ditches, and runways.

The vendor claims that the technology is limited by the moisture content of the soil. The technology is commercially available.

Technology Costs

According to the vendor, the electro-migration technology costs $15 to $50/yd^3 of soil. This price may not include indirect costs such as excavation, permits, and treatment of residuals (D131748, p.18).

Electro-migration was used to treat approximately 1000 yd^3 of gasoline-contaminated soil at a gasoline service station in Sacramento, California. The remediation project cost $20/yd^3 of soil treated, totaling $20,000 (D131748, pp. 8–12).

A field demonstration of the technology was conducted to treat 4000 yd^3 of gasoline-contaminated soil. Costs for the remediation demonstration totaled $5000 (D131748, pp. 13–17).

Information Source

D131748, VISITT 5.0, 1996

T0698

Scientific Ecology Group

Steam Reforming — Synthetica Technologies Detoxifier

Abstract

The Synthetica Technologies Detoxifier (STD) is a commercially available nonincineration device that uses high-temperature steam in a low-oxygen environment to destroy organic components of waste. The STD is used as part of a waste destruction process referred to as steam reforming. The process has been demonstrated on a number of organic liquids such as simple hydrocarbons, alcohols, ketones, and chlorocarbons; along with a variety of polymeric organic materials including paint residues, caulks, shredded paper, plastics, and wood products; and organics adsorbed on soil, debris, activated carbon, and ash. In addition, steam reforming can destroy components found in underground storage tanks such as nitrates, nitrites, and ferrocyanides.

The detoxifier will only treat contaminants that can be volatilized out of the media. Wastes containing nonvolatile metals or compounds must be treated by a different technology to remove the contaminants. Metals may be chemically reduced but will still remain in the waste.

Technology Costs

According to the developer, an STD system ranges in cost from $500,000 to $900,000, which includes installation and a 2-week operator training session. Operating costs, which include capital amortization, electricity, labor, support, and services, are approximately $250 to $500 per day for 24-hr operation (D15377P, p. 4). The estimated price range for treatment is $100 to $200 per drum of waste (D10319V, p. 18).

The developer estimates that activated charcoal wastes, such as used to remove organic vapors during remediation efforts, can be reprocessed using this technology for $0.77/kg. New activated charcoal costs $4.14/kg, resulting in a savings of $3.41/kg by use of the STD (D15292L, p. 10).

An additional estimated cost breakdown comes from Sandia National Laboratory. According to this source, the estimated cost breakdown is the detoxifier, $325,000; drum feeder, $50, 000; and the moving bed evaporator, $165,000. The cost of other peripherals is estimated to be $150,000. Daily operating and maintenance costs are estimated at $600,000. Life-cycle costs are $340,000 (5 years) and $270,000 (10 years). Steam reforming is approximately 75% less expensive that off-site thermal regeneration of granular activated carbon (D17028F, p. 3).

Information Sources

D15377P, Scientific Ecology Group, 1994

D10319V, VISITT 4.0, 1995

D15292L, Galloway and Green, 1995

D17028F, DOE, web page

T0699

SDTX Technologies, Inc.

KPEG

Abstract

The KPEG[SM] process is an ex situ chemical dehalogenation technology for use on soils, sediments, and sludges. Proprietary KPEG is mixed with halogenated hydrocarbons to produce an aromatic ether, which is insoluble in oil and can be separated from the oil. Although historically used to denote potassium polyethyleneglycolate, SDTX uses the service mark KPEG generically to designate any of the family of alkaline glycolate technologies falling under its patents or within the framework of its expertise.

SDTX Technologies, Inc., acquired the pioneering patents (in 1978) and expertise in chemical dechlorination from the Franklin Institute and have supplemented this by funding further work at the National Environmental Technology Applications Center (NETAC). SDTX licensed the patent and technology to SoilTech, Inc., for use at the Wide Beach Superfund site in New York. See Case Study 1 under the SoilTech Anaerobic Thermal Processor (ATP) technology summary (T0717) for further information.

As of early 1999, SDTX Technologies, Inc., was closed for business, and this technology was no longer commercially available.

KPEG is ineffective toward nonhalogenated contaminants.

Technology Cost

According to the vendor, the estimated price range for this technology was $100 to $300 (1995 dollars) per ton. This estimate does not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals. Factors that have a significant effect on unit price include the following:

- Quantity of waste
- Characteristics of soil
- Moisture content of soil (D10334U, p. 17).

Information Source

D10334U, VISITT Version 4.0, 1995

T0700

Seaview Thermal Systems

High-Temperature Thermal Distillation (HT-6)

Abstract

The high-temperature thermal distillation (HT-6) process is an ex situ thermal desorption treatment. This process is a combined incineration and recycling process (D126249, p. 2). HT-6 heats contaminated soil or other solids up to 2000°F (1090°C) in a nitrogen atmosphere and recovers the pollutants for recycling. According to the vendor, this technology can treat soils contaminated with volatile organic compounds (VOCs) and polychlorinated biphenyls (PCBs). The treated soil can then be backfilled in the excavation pits on-site.

According to the vendor, the HT-6 technology is not a destruction process but a separation process technology. The process cleans the soil and concentrates the organics into an organic oil phase. For refinery wastes, coal tar wastes, and creosote, this oil is directly suitable for commercial reuse as a refinery feedstock. The high-temperature thermal distillation technology is not currently commercially available.

The final product, according to Seaview, is chemically stable and meets all federal, state, and local organic land-ban restriction criteria. The vendor states that the HT-6 process distillation removes volatile and semivolatile organic constituents from the water effluent. The process may be adjusted to meet local groundwater standards. In addition, the HT-6 process achieves treatment standards without oxidation, which provides the following advantages:

- Reductions in SO_2, NO_x, and CO_x emissions
- No dioxin precursors generated from processing and degrading emissions
- No by-products of combustion
- No increase in leachability of metals
- No toxic metal particulate emissions
- Versatile on variations in waste (from liquids up to contaminated soils)

The high-temperature thermal distillation technology is not applicable to metal-only wastes, with the exception of mercury, which has a boiling point below 2000°F (1090°C).

Technology Cost

According to the vendor, the treatment cost for high-temperature thermal distillation processing ranges from \$250 to \$350 per ton (\$276 to \$386 per metric ton) of soil treated. This cost varies depending on the amount of soil processed and whether a new unit is set up by the vendor or the waste is transported to an existing unit (D126249, p. 2).

According to the U.S. EPA database, VISITT (version 4.0), the cost for treatment using this technology ranges from \$50 to \$400 per ton (\$55 to \$441 per metric ton) of soil treated. The factors that influence the cost include the quantity of soil treated, the moisture content of the soil, the target contaminant concentration, site preparation, waste handling and preprocessing, and initial contaminant concentration (D10333T, p. 34).

Information Sources

D126249, National Institute of Environmental Health Sciences, web page
D10333T, VISITT, 1996

T0701

Seiler Pollution Controls, Inc.

High-Temperature Vitrification System

Abstract

Seiler Pollution Controls, Inc., has developed the high-temperature vitrification system (HTV) to treat and stabilize hazardous wastes. The process uses a two-stage heating process to melt contaminated materials. The vendor claims that HTV processing can be applied to incinerator fly ash, paint sludge, electroplating and surface finishing residues, wastewater treatment sludge, contaminated solvents and petroleum-based chemicals, asbestos-containing materials, steel manufacturing residues, contaminated soils, and mixed wastes.

As of September 2001, RIMS was unable to contact the vendor by telephone, Internet, or U.S. Mail services. The status of this technology in the United States is uncertain.

The vendor lists the following advantages of the HTV system:

- Modular design can be modified to meet customer needs.
- Unit is compact and transportable.
- System can treat mixed organic/inorganic waste streams without residue or slag.
- Organic contaminants are used as fuel to reduce operating costs.
- Converted wastes are sold, and the owner’s liability is relieved.
- Temperatures can be varied to treat specific waste streams.
- Long operational periods are possible between vitrifier/converter refractory rebuilds.

TABLE 1 Annual Operating Costs of the HTV

Utilities	$35,000
Chemicals	$61,000
Spare parts and maintenance	$54,000
Labor	$460,000
Miscellaneous	$39,000
Total	$649,000

Source: From D19754A.

Pretreatment is required for HTV processing. Drying and size reduction of wastes are required. Additives such as glass formers may be required. Processing of nonhazardous wastes may not be economically feasible. Treatment of radioactive wastes will produce a radioactive glass that requires special handing or treatment.

Technology Cost

In 1996, the vendor estimated the cost of treating incinerator fly ash and gas purification filter dust at $150 to $300 per ton. In a confidential 1996 vendor-supplied report, the cost of treating wastes containing toxic heavy metals and wet wastes was estimated at $300 to $1500 per ton.

Capital and installation costs for a 250-kg/hr HTV system were estimated to range from $2 to $2.5 million. Operating costs were estimated between $100 and $420 per ton. Table 1 shows a breakdown of the annual operating cost (D19754A, pp. 2, 3).

A $10 million facility was constructed in Freiberg, Germany (D20002I, p. 3). This plant processed 10,000 tons of waste per day at a cost of $400 to $450 per ton. The vitrified product was sold at $80 to $100 per ton (D22518D, p. 8; D20002I, p. 3).

In Germany, a $16-million HTV unit vitrifies 6 to 12 metric tons of waste per day (D19996Q, p. 1). In 1997, construction began on a $1.5 million vitrification unit in Coshocton, Ohio (D19009K, p. 10; D20009P, p. 1). The full-scale Ohio facility is expected to cost between $2 and $3.5 million (D19009K, p. 14).

Information Sources

D19009K, Canning, 1997

D19754A, Joint Service Pollution Prevention Opportunity Handbook, 1997

D19996Q, Envirobiz, undated

D20002I, Westergaard, undated

D20009P, Berkshire Information Services, Inc., 1997

D22518D, The Wall Street Transcript, 1997

T0702

Selective Environmental Technologies, Inc. (Selentec)

Electrochemical Ion Exchange (EIX)

Abstract

According to the vendor, the electrochemical ion exchange (EIX) technology is an ex situ process that recovers nitrates from water using ion exchange and uses electrochemistry to destroy the nitrates, leaving no waste products. EIX treats nitrates present in groundwater and plant effluents at concentrations of less than 0.5% by weight. It can be used for community water systems,

individual wells, mine water, and agricultural runoff. The only contaminant treated is nitrate. A pilot project at the Mineral Hills mine (Department of Energy) was started in February 1996.

All information is from the vendor and has not been independently verified.

Technology Cost

EIX was selected by the Mine Waste Technology Pilot Program as the lowest cost option for treating nitrates in mine wastewater. The overall costs are estimated to be less than $0.001/gal of treated water, assuming a 15-year life and 12% interest (D15607K).

Information Source

D15607K, vendor literature

T0703

Selective Environmental Technologies, Inc.

ACT*DE*CON

Abstract

Selective Environmental Technologies, Inc. (Selentec), has developed the ACT*DE*CON^{SM} process for the in situ and ex situ treatment of soils, sludge, and other solid media contaminated with radionuclides and heavy metals. The process uses an oxidative carbonate reaction and a chelating agent to selectively dissolve heavy metals and radionuclides from soils and sediments into an aqueous medium. ACT*DE*CON can process fine silts and clays. Fine sediments are not amenable to conventional soil washing techniques because these technologies often require a secondary processing step for the fine fraction of the soil. The technology has been commercially available since 1997.

Selentec claims the following advantages using ACT*DE*CON:

- Treats soil to regulatory levels.
- May leave natural soil at the site.
- Produces minimal waste (waste volumes $<1\%$ of the feed volume are possible).
- Dissolves minimal amounts of nonhazardous soil materials.
- Allows treated soils to sustain indigenous plant growth.
- Can be regenerated and recycled.
- Reduces cost compared to other stabilization and soil washing technologies.

There are several limitations to the ACT*DE*CON process. The technology does not destroy or stabilize radioactive materials or heavy metals. An additional treatment step is required to stabilize the removed contaminants.

According to the vendor, the technology is site dependent. Contaminants must be accessible to ACT*DE*CON solution. Certain soils, such as zeolites, may interfere with the process solution. Soils with extremely high target contaminant levels may produce large amounts of secondary waste.

Technology Cost

In 1995, ACT*DE*CON was used to treat 3- to 4-g samples of thorium-contaminated soil from a site in St. Louis, Missouri, that is part of the U.S Department of Energy's (DOE's) Formerly Used Sites Remedial Action Program (FUSRAP). Based on the these results, Selective Environmental

Technologies, Inc., estimated that the cost to treat 650,000 yd^3 of similar soil at a rate of 7.5 tons per hour would be \$184.33/yd^3 (D14284H, p. 4).

Information Source

D14284H, Selentec, 1996

T0704

Selective Environmental Technologies, Inc.

MAG*SEP

Abstract
Selective Environmental Technologies, Inc. (Selentec) has developed the MAG*SEP[SM] separation technology for the removal of heavy metals from contaminated groundwater, process liquids, and wastewater. The vendor claims the technology can also treat soil. MAG*SEP can operate in situ or ex situ and is designed to treat large volumes of process liquid containing low levels of contaminants. The MAG*SEP particles consist of magnetic grains embedded in a resin shell. The outer layer of the resin shell is either composed of a specific functional group or embedded with particles of ion exchange material. The technology is commercially available.

According to the vendor, the benefits of MAG*SEP technology include:

- Removes heavy metals from groundwater or effluent streams.
- Can treat waste streams with high levels of suspended solids without pretreatment.
- Can be applied as an in situ or ex situ technique.
- May be regenerated and recycled.
- Generates minimal secondary wastes.

MAG*SEP may have difficulty in preferentially removing one metal from a contaminant stream containing several different metals. Some problems have been encountered when the target metal is present in different oxidation states. Liquids with low pH may be difficult for MAG*SEP to process.

Regenerated MAG*SEP particles still contain residual contaminants. The regenerated particles should not be recycled in different applications due to the possibility of cross contamination. However, the regenerated particles are safe to use during the same cleanup operation.

Technology Cost
According to data published in 1997, a process using MAG*SEP particles to remove contaminants from a wastewater stream would cost from \$0.0019 to \$0.005/gal. The authors state that treating the same waste stream using ion exchange resins would cost between \$0.003 and \$0.018/gal of water treated, and the cost for filtration/precipitation would be approximately \$0.054/gal. Treatment costs were said to be dependent on contaminant loading and water chemistry (D17470T, p. 3).

In 1995, the vendor estimated that capital, installation, and operation costs for the first year of operation of a 2000-gal/min MAG*SEP system would be under \$1 million (D112867, p. 2).

Information Sources

D112867, Initiatives Online, 1995
D17470T, Dunn et al., 1997

T0705

Separation and Recovery Systems, Inc.

SAREX Chemical Fixation Process

Abstract
The SAREX™ chemical fixation process (CFP) is a commercially available, ex situ thermal and chemical reactive (fixation) process. The process removes volatile organic compounds (VOCs) and selected semivolatile organic compounds (SVOCs) from the waste stream and stabilizes the remaining organic and inorganic constituents in sludges or soils. In addition, the vendor claims the technology treats heavy metals; fats, oils, and grease (FOG); polycyclic aromatic hydrocarbons (PAHs); and some pesticides/herbicides. The SAREX CFP uses specially prepared lime and proprietary, nontoxic chemicals (a reagent blend). The reagent blend is mixed proportionally to catalyze and control the reactions. The treated product can be easily backfilled and compacted on-site.

The SAREX CFP can be applied as either an "open" system or a "closed" system, differing only in the manner in which the contaminated matrix and reagents are handled. The closed system is used when the release of hazardous fumes or vapors may occur. This technology is commercially available.

Advantages of the SAREX CFP include the following:

- Improves leachate characteristics by reducing the liquid content in the waste.
- Treats wastes with high concentrations of hydrocarbons.
- Decreases surface area of contaminated material.

The SAREX CFP is not applicable for wastes that contain lead.

Technology Cost
The estimated capital cost of using a SAREX CFP system to treat contaminated sediment is $1,000,000 (D12618B, p. 7). The operating cost for a closed system application of this technology ranges from $65 to $85 (1996 dollars) per metric ton. The cost to operate this technology as an open system is considerably lower (personal communication: Christopher Hebble, SRS, 1997).

Information Source

D12618B, REMTEC Report, 1996

T0706

Separation and Recovery Systems, Inc.

SAREX Process

Abstract
The SAREX® process is a trailer/skid-mounted, modular system designed for on-site, in-line separation and resource recovery of oily waste sludges and contaminated soils. This process provides dewatering and thermal desorption to maximize the recovery of oil while obtaining substantial reduction in volume and contaminant concentrations. The SAREX process includes the MX-1500 centrifuge, the MX-2000 low-temperature thermal dryer, and the MX-2500 medium-temperature thermal desorber. The MX-1500 centrifuge is used to separate the solids from the

oil and water phases. The MX-2000 is used to thermally desorb any water and light hydrocarbons in the centrifuged solids. The MX-2500 is used to thermally desorb any remaining, high-boiling-point, semivolatile organics contained in the dried solids.

The SAREX process is applicable for the treatment of typical soils and sludges generated from refineries and manufactured gas plants, as well as coal tar wastes and wood treatment waste. The vendor claims that this technology has been demonstrated on polychlorinated biphenyls (PCBs), mixed wastes, dioxin, furan, and both volatile and semivolatile organic compounds (VOCs and SVOCs). The SAREX process is no longer commercially available from this vendor.

According to the vendor, the SAREX process has several advantages:

- Achieves over 90% volume reduction.
- Is Resource Conservation and Recovery Act (RCRA) exempt and meets closed-loop exclusion status.
- Is cost competitive with incineration and cement kiln disposal.
- Has the flexibility to treat varied waste streams.
- Achieves levels of total petroleum hydrocarbons (TPH) typically below 200 parts per million (ppm) in the processed solids.

If the material is sludgelike, additional fluids may need to be added to improve separation in the centrifuge.

Technology Cost

According to the vendor, the treatment cost of centrifuging and thermal desorption will depend on a number of factors including waste quantities, utilities, health and safety considerations, location permitting, time of the year, material characteristics, and treatment objectives. The typical cost to dewater, deoil, and dry refinery sludges ranges from $20 to $300 (1994 dollars) per feed ton. This cost depends on the treatment objectives and the quantity and viscosity of the raw material. This cost does not reflect the economic benefits of reusing oil recovered from the process. The typical cost to remediate soils containing VOCs is $50 to $150 (1994 dollars) per feed ton. This cost depends on the soil quantity, optimum throughput, and treatment objectives. The typical cost to remediate soils containing SVOCs, PCBs, or mercury is estimated at $80 to $250 (1994 dollars) per feed ton (D14194G, p. 8).

The vendor states that the costs for mobilization and demobilization of the thermal desorption equipment range from $50,000 to $150,000 (D14687W, p. 288). Capital costs for the thermal desorption systems range from $100,000 for the MX-1500 to $800,000 for the MX-2500 (D126205, p. 9; D126216, p. 12; D126227, p. 15).

Information Sources

D126205, Water Technology International Corporation, 1996

D126216, Water Technology International Corporation, 1996

D126227, Water Technology International Corporation, 1996

D14194G, Miller, 1994

D14687W, Miller et al., 1994

T0707

Separation Dynamics, Inc.

EXTRAN

Abstract

EXTRAN™ is a separation technology designed to continuously clean the fluid in an aqueous parts washer. The technology separates free oil, emulsified oil, and particles from parts washing water. A slip stream of contaminated parts washing fluid is continuously filtered out of the parts washing system to be treated. After treatment, cleaned water and soluble detergents are returned to the washer. According to the vendor, the technology has been field tested using both pilot-scale and commercial systems.

The vendor claims the following advantages for the technology:

- Improved parts washing performance
- Reuse of cleaning chemicals
- Minimization of waste
- Reduced labor

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0708

Serengeti Products Company, Inc.

Oil Snapper Soil Remediator

Abstract
The Oil Snapper™ soil remediator is a nutrient formulation designed to enhance the activity of soil microbes, leading to faster bioremediation of petroleum hydrocarbons. It can be used with either indigenous soil microbes or added commercial microbes and is absorbent to prevent runoff and control odors when applied to spills. Oil Snapper may be used to improve bioremediation processes in treatment cells, biopiles, landfarms, or for in situ bioremediation.

The Oil Snapper product is based on Serengeti's Enhanced Urea Technology™ and contains the minerals and chemical compounds needed by microbes to degrade petroleum hydrocarbons. This product is applicable to soils contaminated with most petroleum hydrocarbons, including diesel, No. 6 fuel oil, hydraulic oil, and crude oil.

The vendor also suggests using the product as a soil maintenance tool, whereas a program of biomaintenance will prevent the small leaks and drips associated with normal work from accumulating into larger problems in the future.

The Oil Snapper technology was developed by Serengeti Products Company, Inc., which also owns the rights to the technology. Oil Snapper is currently used by industry for site bioremediation as well as for on the spot cleanup of leaks and spills and is commercially available.

Technology Cost
The Oil Snapper soil remediator is available by the 2-ft^3 (56-liter) bag or may be purchased in bulk on 15-, 25-, or 50-bag pallets. Prices per bag and per pallet are lower when purchasing in bulk. Prices range from $18.00 per bag when purchasing 20 or more 50-bag pallets to $25 per bag when purchased individually.

According to the vendor, the product should be applied to hydrocarbon-contaminated soils at a volume ratio of approximately 1 part Oil Snapper to 25 parts soil. When applied to fresh spills, 4 bags of Oil Snapper are required for each drum of hydrocarbons spilled. Table 1 displays Serengeti's pricing as of 1997. Shipping charges are not included in the price (D177371, p. 5).

Information Source

D177371, Serengeti Products Company, Inc., 1998

TABLE 1 Oil Snapper Retail Price List

Purchase Volume	Retail Price (dollars per pallet)
When Purchased in 50-Bag Pallets	
Over 20 pallets	$900.00
10–19 pallets	$950.00
1–9 pallets	$1,000.00
When Purchased in 25-Bag Pallets	
25-Bag Pallet	$550.00
When Purchased in 15-Bag Pallets	
15-Bag Pallet	$345.00

Source: D177371, p. 5.
Note: Prices shown do not include shipping.

T0709

Sevenson Environmental Services, Inc.

MAECTITE Chemical Treatment Process

Abstract
Sevenson Environmental Services, Inc. (Sevenson), is the owner of the MAECTITE® chemical treatment process for the precipitation and stabilization of toxic heavy metals. Chemical treatment by the MAECTITE process converts leachable lead, hexavalent chromium, or other heavy metals into insoluble minerals and mixed mineral forms within the material or waste matrix. The technology can be used as an in situ or an ex situ method and does not use pozzolanic or siliceous binders to stabilize the treated material.

The vendor states that over 600,000 yd^3 of material have been treated by the MAECTITE process. The technology has been used in over 400 bench-scale treatability studies and over 50 full-scale cleanups. These operations have taken place in 26 states and in all 10 EPA regions.

Sevenson claims that MAECTITE technology converts heavy metals and radionuclides in soil, groundwater, solid waste, debris, sludges, and other material into nonleachable forms that are stable over geological time spans. They also claim that the technology limits the bioavailability of lead in treated soil and can result in volume reduction with limited mass increase during treatment.

Sludges treated with MAECTITE technology may require dewatering to comply with the free liquid statute for land disposal. Temperatures less than 25°F slow process reactions and increase the viscosity of process liquids. Frozen soil can also interfere with treatment. Multivalent metallic cations may require redox manipulation during treatment. In addition, the technology may not be effective at treating soils with high concentrations of organic contaminants.

Technology Cost
In 1996, Sevenson Environmental Services, Inc. (Sevenson), estimated that treating contaminated soil using its MAECTITE technology would cost between $5 and $170 per ton. This estimate may not include all indirect expenses associated with treatment, such as excavation, permitting, and residual treatment costs. The following factors can have the greatest effect on costs:

- Initial contaminant concentration
- Target contaminant concentration
- Characteristics of the soil

- Quantity of waste
- Geochemical characteristics of the treatment material
- In situ versus ex situ treatment (D15712K, p. 46)

Factors having a secondary impact on treatment costs include the depth of contamination, the depth to groundwater, site preparation costs, and waste handling and preprocessing costs. Other factors include utility/fuel rates, labor rates, the amount of debris associated with the waste, the characteristics of the residual wastes, and the moisture content of the soil (D15712K, p. 46). In 1998, the vendor estimated that the MAECTITE process costs 30 to 70% less than cement encapsulation (D17813W, p. 1).

The Marathon Battery Superfund site in Cold Springs, New York, was treated using the ex situ MAECTITE process. The site, which includes a sensitive aquatic ecosystem, was contaminated with lead and cadmium (D15657U, p. 4). Total costs for the remediation project were less than $91,000,000 (D220939, pp. 1, 2).

At a battery recycling facility in Iowa, an uncontrolled dump site was treated using both in situ and ex situ applications of MAECTITE technology. Concentrations of lead in the untreated soil were as high as 80 mg/liter. According to the vendor, approximately 52,000 yd^3 of soil were treated at an average cost of $14.75 per ton. Lead concentrations in treated soil were below 5.0 mg/liter (D15712K, pp. 8–11).

At the Zabel Battery Superfund site, an in situ application of MAECTITE technology was used to treat 17,500 tons of material consisting of soil, batteries, battery casings, debris, scrap metal, railroad ties, white goods, rubble, and wood. The site covered 0.5 acres, and treatment reached a depth of 1.5 ft. The vendor states that project costs were approximately $420,000 (D15712K, pp.29–32).

MAECTITE technology was used to treat excavated and screened firing range soil at Fort Ord in California. Approximately 1300 yd^3 of soil were treated. Costs were estimated at $60/$yd^3$ of soil treated (D15712K, pp. 24–26).

Sevenson also reported that MAECTITE was used at the Dundalk Marine Terminal in Baltimore, Maryland. At this site, approximately 8000 tons of soil were contaminated with chromite ore residuals that had been used as fill material. The costs for the project were estimated a $170/$yd^3$ (D15712K, pp. 18–21).

At Kirtland Air Force Base in New Mexico, an in situ application of MAECTITE was used to treat 2000 yd^3 of soil contaminated with lead and cadmium. Following MAECTITE treatment, leachable lead and cadmium levels in soils were less than residential human health standards. In addition, contaminant levels were low enough that the treated waste could be categorized as nonhazardous by Resource Conservation and Recovery Act (RCRA) standards. Total costs for the project were $125,000, which was almost 40% less than alternative stabilization techniques considered at the site (D21483F, p. 3).

Information Sources

D15712K, VISITT 5.0, 1996

D17813W, Sevenson Environmental Services, Inc., 1998

D21483F, U.S. EPA, 2000

D220939, Advanced GeoServices Corp., undated

T0710

Sheet Piling — General

Abstract

Sheet pilings are large rectangular plates, generally made of steel, that are driven into the ground to form underground walls for the containment and control of groundwater and/or soil gases.

Sheet piling barriers can be successfully used for many remediation situations:

- Deep enclosures around waste sites or landfills to prevent migration of liquid or gaseous contaminants in soil or water
- Shallow barriers to control lightweight contaminants that float on the water table
- Temporary barriers during remediation or removal
- Shoreline barriers to prevent seepage from soil into waterways
- Isolation of accidental spills
- Directing contaminant plumes toward pump-and-treat operations

Further information about similar technologies may be found in:

- T0667, Waterloo Barrier™
- T0424, IET, Inc. Barrier System
- T0601, Treatment Walls—General

Technology Cost
No available information.

T0711

Shirco Infrared Systems, Inc.

Shirco Infrared Thermal Destruction System

Abstract
The electric infrared incineration technology is a mobile thermal processing system that is suitable for soils or sediments contaminated with organic compounds, polychlorinated biphenyls (PCBs), and metals. Liquid organic wastes can be treated after mixing with sand or soil. Electrically powered silicon carbide rods heat organic wastes to combustion temperature while any remaining combustibles are incinerated in an afterburner.

Solid waste must be within a range of 5 μm to 2 inches to be treated by the Shirco technology. Large bulk objects must be shredded to this size prior to treatment.

The technology, originally developed by Shirco Infrared Systems, Inc., of Dallas, Texas, is no longer available through vendors in the United States. It is commercially available through Gruppo Italimpresse, located in Rome, Italy.

Technology Cost
An economic analysis was conducted by the U.S. Environmental Protection Agency (EPA) in 1989, based on the processing of 36,500 tons of waste feed in a commercial unit. This quantity is base on the amount of waste that would be processed if the unit operated at the design capacity of 100 tons per day and a 100% operating factor over a 365-day period. Costs were adjusted to reflect real-time operations of the unit since periodic shutdowns are required in order to respond to maintenance or operational problems. Costs were based on operating factors ranging from 50 to 85%, equivalent to a range of 429 to 730 days at the site to process the 36,500 tons of waste feed (D14359J, p. 5, 31–33). The results of the economic analysis are presented in Table 1. Depending on the operational parameters of a particular site, costs can be estimated by applying the particular throughput to the Table 1 (in 1989 dollars). A summary of the estimated costs for five other sites is presented in Table 2 (D14358I, p. 87).

TABLE 1 Economic Model for Shirco Transportable Infrared Incinerator

Cost Categories	$ Millions per Year	$ per Ton
Capital cost		
Direct—depreciable	3.25	—
Indirect—depreciable	0.66	22.60
Indirect—nondepreciable	.70	23.97
Operating and maintenance costs		
Variable	.24	8.21
Labor	0.85	29.11
Living	0.48	16.44
Maintenance	0.39	13.36
Analyses	0.10	3.42
Mobilization/demobilization	0.80	27.40
Transportation/setup and on-site checkout	0.16	5.48
Site permit	0.10	3.42
Working capital	0.05	1.71
Decontamination/demobilization	0.05	17.12
Fixed	0.72	24.66
Total cost per ton		196.90

Source: D14358I, U.S. EPA, 1988.
Note:

1. Unit capacity at 100 tons per day.
2. Eighty percent on-stream factor at 292 days per year.
3. Total annual throughput at 29,200 tons.
4. Equipment life at 10 years.
5. Unit a specific site for one year.
6. Utilities consumption estimate: 1200 max installed kilovolt ampere; 2200°F afterburner temperature; 300 installed horsepower; 140 gal/min water usage.
7. Labor estimates: 16 operators at $10.50/hr and 2 overtime hours per week; 3 supervisors at $20/hr; 3 lab/safety at $11.50/hr; 50% overhead rate; $75/ day per diem for 16 personnel.

TABLE 2 Economic Analysis Using the Shirco Infrared Incinerator Based on the Processing of 36,500 Tons of Waste Feed in Commercial Unit

Data Source	Unit Capacity	Operating Factor (%)	Unit Cost ($/ton)
Brio Site—Friendswood, Texas (Shirco cost estimate)	150	82	143[a]
	220	82	119[a]
LaSalle Electric—LaSalle, Illinois (Haztech proposal)	100	60	300[a]
Florida Steel—Indiantown, Florida (OH Materials estimate)	100	61	<300[b]
Peak Oil—Brandon, Florida (SITE Tech. Eval. Report)	100	80	197[c]
		37	416[c]
ECOVA—Dallas, Texas (vendor's claims)	100	85	161–257[a]

Source: D14359J, U.S. EPA, 1989.
[a] Cost includes vendor profit but excludes waste excavation, feed preparation, and ash disposal.
[b] Cost includes vendor profit, waste excavation, and feed preparation but excludes ash disposal.
[c] Cost excludes vendor profit, waste excavation, feed preparation, and ash disposal.

Information Sources

D14359J, U.S. EPA, 1989
D14358I, U.S. EPA, 1988

T0712

SIVE Services

Steam Injection and Vacuum Extraction

Abstract
Steam injection and vacuum extraction (SIVE) is a patented, commercially available in situ technology. SIVE has been used to remove non-aqueous-phase liquids (NAPLs), diesel fuel, jet fuel, semivolatile and volatile organic compounds (SVOCs and VOCs), chlorinated solvents, acetone, and benzene, toluene, ethyl benzene, and xylenes (BTEX) from soil and groundwater.

During SIVE applications, traditional soil vapor extraction (SVE) is augmented by steam, which is injected into the subsurface. The steam vaporizes volatile and semivolatile contaminants and displaces liquids in soil pores. Both vapor and liquids are then pumped to the surface via extraction wells.

According to the vendor, SIVE is less expensive than traditional excavation and treatment, pump-and-treat, or SVE approaches. They also state that the system can run without constant supervision, requires less cleanup time, and effectively remediates organics more quickly than other systems—typically weeks as opposed to months or years.

Local geology may effect system efficiency. Compound with high boiling points may need to be extracted in the liquid phase. Although the overall cost is normally less than traditional SVE treatment because of the lessened remediation time, the initial costs of capital equipment and energy are greater than that of traditional systems. SIVE is not effective at removing metals, although the presence of metals does not affect its ability to remove organics.

See also In Situ Steam-Enhanced Extraction—General (T0407).

Technology Cost

According to the vendor, cost estimates for the SIVE technology range from \$10 to \$100/yd^3 depending on site characteristics.

The number of wells required per unit area is the most significant factor influencing overall costs for stationary steam extraction systems. The number of wells is related to the depth of contamination and soil permeability. Shallow contamination requires less space between wells and lower operating pressures to prevent soil fracturing. Deeper contamination allows higher operating pressures and greater well spacing, and thus fewer wells. The more wells required per unit area, the higher the capital cost and the cost of remediation (D12529B, p. 6).

The entire remediation budget for the San Jose solvent site was \$948,000 for capital costs and \$1,172,000 per year for operation and maintenance costs. The budget included remediation activities using several different technologies. The SIVE pilot test was estimated to cost \$100/yd^3 (D19966K, p. 3; D10330Q, p. 10).

At the Lemoore Naval Air Station, remediation costs are estimated to be \$200 per ton of contaminated soil (D12776O, p. 1)

At a site contaminated with soil concentrations of up to 5000 mg/kg and groundwater concentrations of approximately 60 mg/liter of chlorinated aromatics, SIVE technology remediation took a fraction of the time and cost 30 to 50% less than excavation and aboveground treatment (D10225Q p. 61).

Information Sources

D10225Q, Noonan et al., June 1993
D10330Q, VISITT 4.0, undated
D12529B, U.S. EPA, May 1991
D12776O, United States Navy, 1996
D19966K, U.S. EPA, 1999

T0713

Slurry Walls — General

Abstract

Slurry walls are an in situ barrier technology used to contain contaminated groundwater; divert contaminated groundwater from drinking water intake; divert uncontaminated groundwater flow; and/or provide a barrier for a groundwater treatment system. There are different materials, and combinations of materials that can be used to construct slurry cutoff walls including soil–bentonite, cement–bentonite, and plastic concrete. Barriers consist of a vertically excavated, slurry-filled trench. The slurry hydraulically shores the trench to prevent collapse and forms a filter cake to reduce groundwater flow. Slurry walls are often used where the waste mass is too large for treatment and where soluble and mobile constituents pose an imminent threat to a source of drinking water.

Slurry walls have been used in the construction industry for over 45 years, and, as a result, the requirements and practices for designing and installing a slurry wall are well established. Since 1970, slurry walls have been used for pollution control and the technology is regarded as an effective method of isolating hazardous waste and preventing the migration of pollutants. The process of selecting the proper mix of barrier materials to contain specific contaminants is less well developed and requires compatibility testing. Excavation and backfilling of the trench is critical and requires experienced contractors.

Advantages of slurry walls include:

- Construction techniques are well understood, practiced, and accepted.
- Installed up to depths of 400 ft.
- Can be used in conjunction with other remediation technologies.

Factors that may limit the applicability and effectiveness of the process include:

- Technology only contains contaminants within a specific area.
- Soil–bentonite backfills degrade in the presence of strong acids, bases, salt solutions, and some organic chemicals.
- Installation produces a substantial amount of spoils requiring disposal.
- Difficult to ensure proper emplacement.
- Assessment of performance is difficult.

The RIMS library/database contains several technologies that use high-density polyethylene (HDPE) to form composite barriers. These include GSE Lining Technology, Inc., GSE Curtain Wall Vertical Membrane Barrier System (T0357) and Horizontal Technologies Inc., Polywall Barrier System (T0375). Information on a related technology, Treatment Walls—General (T0601) is also provided.

Technology Cost

Costs likely to be incurred in the design and installation of a standard soil–bentonite wall in soft to medium soil range from \$540 to \$750/m^2 (\$5 to \$7/ft^2) (1991 dollars). These costs do not include variable costs required for chemical analyses, feasibility, or compatibility testing. Testing costs depend heavily on site-specific factors (D109308, p. 2). The installation cost of a cement-based slurry wall ranges from \$10 to \$20 per vertical square foot for a 2-ft-wide barrier of less than 100 ft in depth (D18976I, p. 6).

Factors that have the most significant impact on the final cost of soil–bentonite slurry wall installation include:

- Type, activity, and distribution of contaminants
- Depth, length, and width of wall
- Geological and hydrological characteristics
- Distance from source of materials and equipment
- Requirements for wall protection and maintenance
- Type of slurry and backfill used
- Cleanup, treatment, and disposal of spoils
- Other site-specific requirements as identified in the initial site assessment (i.e., presence of contaminants or debris) (D109308, p. 2; D18976I, p. 5)

Generally, there is a substantial cost increase associated with emplacing slurry walls at depths greater than 90 ft (D16334I, p. 2).

Information Sources

D109308, http://pipes.ehsg.saic.com/section4/4_41.html
D16334I, U.S. EPA, 1992
D18976I, Pearlman, 1999

T0714

Smith Environmental Corporation

Battery Waste Treatment Process

Abstract

Smith Environmental is the owner of the battery waste treatment process (BWTP), a technology that uses washing, liberation, and gravity separation to treat waste from battery wrecking operations. Treatment by the BWTP process typically yields rubber, plastic, and a concentrated lead product. The vendor claims this is a closed-loop system where all water used in the process is recycled. The technology was commercially available and had been used for full-scale cleanups in 1995. RIMS were unable to obtain information from the vendor, so current commercial availability is unknown.

The vendor claims that the BWTP system uses existing physical separation equipment to partition wastes. BWTP results in no additional toxic chemical being brought on-site and no discharge of toxic chemicals off-site. The vendor claims that up to 80% of the source material can be removed as products that can be recycled. The remaining material is stabilized for on-site disposal.

The BWTP system will not treat materials containing chemically combined lead in low concentrations. Furnace products (such as ash) must be treated by another technology (such as

stabilization). All information in this summary was provided by Canonie Environmental Services Corporation in 1995 and has not been independently verified.

Technology Cost

In 1995, Canonie Environmental Services Corporation (which then owned the technology) estimated that treating waste using the battery waste treatment process (BWTP) would cost between \$100 and \$150 per ton. This estimate stated that price estimates may not include all indirect costs associated with treatment, such as excavation, permits, and treatment of residuals. Factors listed as having a significant effect on costs include (in decreasing order of importance) quantity of waste, the characteristics of the residual wastes, waste handling and preprocessing costs, the amount of debris associated with the waste, the depth of the contamination, and the site preparation costs (D10190W, p. 24).

Information Source

D10190W, VISITT 4.0, 1995

T0715

Smith Environmental Technologies Corporation

Low-Temperature Thermal Aeration

Abstract

The low-temperature thermal aeration (LTTA) technology is a thermal desorption process that separates chlorinated hydrocarbons, volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), pesticides, and petroleum hydrocarbons from soils at temperatures of 300 to 800°F. This technology uses hot air to desorb contaminants from soil into a contained airstream and treats the airstream before discharging it to the atmosphere. The system is transportable and consists of six major components assembled on flat-bed trailers. The entire system and support areas require approximately 10,000 ft^2 of operating space.

The LTTA technology was demonstrated for removal of pesticides from soil in the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program in September 1992 at an abandoned pesticide mixing site in western Arizona. This technology has also been used to remove VOCs and SVOCs in full-scale applications at five other sites. The technology is commercially available.

Dioxins and furans are not produced in LTTA system. Extremely low levels were found in the stack gas during the SITE demonstration study.

The LTTA technology is best suited for soils with a moisture content of less than 20%; those with a moisture content greater than 20% may need dewatering. Crushing or screening prior to treatment may be required for oversized materials (greater than 2 inches in diameter). Clay shredding may be required for some applications. The air pollution control system of the LTTA process may include a thermal oxidizer or afterburner to destroy organics and a quench tower to cool the airstream when LTTA is used to treat soils contaminated with high concentrations of petroleum hydrocarbons.

Technology Cost

Based on data from the U.S. EPA SITE demonstration program, treatment costs were estimated for treating soil at various processing rates. At a rate of 20 tons per hour, total fixed and variable

TABLE 1 Detailed Breakout of Total Fixed and Variable Costs to Process 10,000 Tons of Soil at Various Processing Rates

Cost Category	Costs ($) at 20 Tons per Hour	Costs ($) at 35 Tons per Hour	Costs ($) at 50 Tons per Hour
Site preparation	26,250	26,250	26,250
Permitting/regulatory	22,000	22,000	22,000
Equipment	439,450	258,500	180,950
Startup	264,810	264,810	264,810
Labor	398,820	234,600	335,140
Consumable materials	387,260	227,800	159,460
Utilities	0	0	0
Effluent monitoring	52,000	52,000	52,000
Residual waste shipping, handling, and transportation	28,900	17,000	11,900
Analytical	204,000	120,000	84,000
Equipment repair and replacement	122,400	72,000	50,400
Site demobilization	141,840	141,840	141,840
Total	2,087,730	1,436,800	1,328,750
Cost per ton	209	144	133
Cost per metric ton	230	159	147

Source: From D10956I.

costs are $209 per ton. For processing rates of 35 and 50 tons per hour, total fixed and variable costs are $144 and $133 per ton, respectively. Table 1 gives a detailed breakdown of total fixed and variable costs (D10956I, p. 22).

The LTTA system was assumed to operate for approximately 30 hr per week. No equipment cost alternatives are presented because the full-scale system is the only model available. Consumption rates for electrical, water, and telephone utilities were assumed negligible in terms of overall LTTA system operating costs (D10956I, pp. 26, 27).

According to the vendor, the full-scale remediation of contaminated soil at the McKin Superfund site in Gray, Maine, was $2,900,000. This figure included the costs for salaries and wages, rental, supplies, subcontractors, fuel, and other professional services. It did not include the expenses associated with mobilization, site characterization, pilot-scale treatability testing, waste material disposal, site closure, or demobilization (D14110W, p. 64).

An LTTA system was used to remediate 41,431 tons of pesticide-contaminated soil at the Arlington Blending and Packaging Superfund site in Arlington, Tennessee. The total project cost was $5,586,376. This figure included $4,293,893 for capital; $62,351 for operation and maintenance; $633,528 for analysis, excavation, and waste disposal; and $596,604 other project costs (D212340, p. 5; D21038Y, p. 57).

Information Sources

D10956I, U.S. EPA, 1995

D14110W, Federal Remediation Technologies Roundtable, 1995

D21038Y, Federal Remediation Technologies Roundtable, 2000

D212340, U.S. EPA, 2000

T0716

Smith Technology Corporation

Pyrokiln Thermal Encapsulation

Abstract
Many Superfund sites have soils contaminated with organic and heavy-metal wastes. Thermal treatment of these soils destroys the organic fraction, leaving the heavy metals in the ash. The Pyrokiln thermal encapsulation process is an ex situ treatment technology that is designed as an enhancement to conventional rotary kiln hazardous waste incineration. The technology combines fluxing reagents with the waste material to increase slagging or thermal encapsulating reactions near the kiln discharge, which stabilize metals in the ash.

This technology is meant to treat soils and sludges contaminated with organics and metals. Organics species that may be treated include halogenated and nonhalogenated organics and petroleum products. According to the vendor, metals that may be stabilized include antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, selenium, silver, thallium, and zinc. This process may also apply to mixed waste. The product toxicity characteristic leaching procedure (TCLP) results exceeded Environmental Protection Agency (EPA) limits for higher feedstock chromium concentrations during the second-year tests. The product met EPA limits for lead, cadmium, and chromium during the first-year tests. The technology is commercially available.

Low soil moisture allows bed slipping and sliding as opposed to tumbling, which promotes agglomeration and agglomerate growth. The moisture content of soil to be treated by this method should be between 15 and 18%.

Technology Cost
No available information.

T0717

Smith Technology Corporation

SoilTech Anaerobic Thermal Processor (ATP)

Abstract
The SoilTech anaerobic thermal processor (ATP) technology is a physical separation process that thermally desorbs organics such as polychlorinated biphenyls (PCBs) from soil and sludge. The SoilTech system distills organic contaminants from a solid matrix in an anaerobic environment, thus preventing oxidative degradation of contaminants such as PCBs into more harmful reaction products. Contaminants are collected in an oily condensate, which is disposed.

The SoilTech ATP system is a type of indirectly fired rotary kiln. The system treats soils, sediments, and sludges contaminated with compounds that vaporize at temperatures up to 1100°F (590°C), resulting in treated solids that are free of organics and suitable for on-site backfill. The treatment system uses filtration, oxidation, and adsorption operations to remove contaminants from aqueous condensate.

According to the vendor, the removal efficiencies for PCBs in treated soil averages 99.98% and dioxin related compounds (DRCs) of greater than 99.99999% are common. Applicable contaminants include the following:

- Petroleum hydrocarbons
- Halogenated hydrocarbons

- Aromatic hydrocarbons
- Volatile metals

High moisture content (greater than 20%) and/or high silt/clay content (greater than 20 to 30%) may reduce the process throughput and increase treatment costs (D10443Y, p. 2). Prescreening and/or crushing may be necessary if material is smaller than 2 inches (5 cm) in diameter. Co-feeding of coarse material may be necessary if a material contains a high percentage of very fine material, such as clay. Fine material reduces the efficiency of the sand seals and will be drawn out of the processor with the flue gases, reducing the quantity of material available for heat transfer in the heat recovery and cooling zones (D12494H, p. 216).

The processor treats wastes containing contaminants with low boiling points more effectively than wastes containing contaminants with high boiling points. However, organics with high boiling points, such as PCBs and polycyclic aromatic hydrocarbons (PAHs), can be reduced to concentrations below detection limits of 1 ppm. Additionally, the ATP system is specifically designed to treat wastes with a 10% hydrocarbon concentration (D10443Y, p. 2).

Technology Cost

During an evaluation of the SoilTech ATP system for the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration program, treatment costs were estimated to range from \$150 to \$250/ton (1994). Treatment costs are determined by the following factors (D12494H, p. 215):

- Moisture content of feed material
- Particle size
- Hydrocarbon content
- Material handling characteristics
- Chemical characteristics

TABLE 1 Cost in Dollars of ATP Application at the Wide Beach Development Superfund Site

Cost Category	Total Cost (\$)	Cost per Ton (\$)
Site preparation and mobilization[a]	588,000	14
Permitting and regulatory	200,000	5
Capital equipment	2,153,000	51
Startup	133,000	3
Labor	3,800,000	90
Supplies and consumables	1,194,000	28
Utilities	913,000	22
Effluent monitoring[b]	—	—
Residual and waste handling and transporting[c]	736,000	19
Analytical services	320,000	8
Equipment repair and replacement	1,982,000	47
Site demobilization	481,000	11
Total	\$12,500,000	\$298/ton

Source: Adapted from D17023A.

[a] Does not include the cost of constructing a concrete pad for the unit.

[b] Included under analytical services.

[c] Does not include costs for site-specific requirements.

TABLE 2 Cost in Dollars of ATP Application at the Waukegan Harbor Superfund Site

Cost Category	Total Cost ($)	Cost per Ton ($)
Site preparation and mobilization	655,000	51
Permitting and regulatory	188,000	15
Capital equipment	361,000	28
Startup	158,000	12
Labor	854,000	67
Supplies and consumables	139,000	11
Utilities	65,000	5
Effluent monitoring	207,000	16
Residual and waste handling and transporting	186,000	15
Analytical services	38,000	3
Equipment repair and replacement	133,000	10
Site demobilization	390,000	31
Total	$3,374,000	$264/ton

Source: Adapted from D17023A.

Mobilization and demobilization costs for the 10-ton (9-metric-ton) per hour SoilTech system range from $700,000 to $1.5 million (D12494H, p. 216).

Total cost for the Wide Beach Development site was $12,500,000, or $298 per ton of soil treated. Total cost for the Waukegan Harbor Superfund site was $4,274,000, or $264 per ton of soil treated. Direct treatment costs for Waukegan were $3,374,000 and the mobilization costs were $900,000 (D194869, pp. 16–17). Costs associated with the SITE demonstrations are summarized in Tables 1 and 2.

Information Sources

D12494H, Hutton and Shanks, Spring 1994

D17023A, EPA Draft Applications Analysis Report, March 1993

D194869, U.S. EPA, 1995

T0718

Smith Technology Corporation

Two-Phase Vacuum Extraction

Abstract

Two-phase vacuum extraction (TPVE) is a patented, commercially available, technology for the treatment of soil and groundwater contaminated with volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs). TPVE applies a vacuum to a well or trench in the contaminated region to simultaneously extract both soil vapor and groundwater. Contaminants that are dissolved or suspended in groundwater are removed while vapor flow through the vadose zone results in volatilization and enhanced biodegradation. TPVE is unique in that the water extracted under vacuum is used to serve the sealing, cooling, and/or heating requirements of the vacuum extraction system.

According to the vendor, the major benefits of TPVE are (1) that the rate of liquid extraction can be greatly increased over that of conventional pumping, (2) the technology lowers the water table, exposing contaminants that were previously trapped below the water table, (3) the reduced need (and expense) of additional makeup water, and (4) achieving vapor condensation

and dehumidification without relying on external energy sources reduces costs and facilitates the use of the technology at remote locations.

All information is from the vendor and has not been independently verified.

Technology Cost

No available information.

T0719

Soil/Sediment Washing — General

Abstract

Soil washing is a generic treatment technology that is offered by several vendors. The technology is an ex situ, water-based process for scrubbing soils to remove contaminants. Soil washing incorporates methods from established mining, mineral processing, ore benefaction, and wastewater treatment technologies, especially for full-scale systems. The process removes contaminants in one of two ways: by dissolving or suspending contaminants in the wash solution or by concentrating the contaminants into a smaller volume of soil through particle size separation, gravity separation and attrition scrubbing.

Generally, soil washing is not a stand-alone technology but is commonly used with bioremediation, incineration, and solidification/stabilization. The target contaminant groups for soil washing are semivolatile organic compounds (SVOCs), fuels and inorganic contaminants, especially heavy metals. Some soil washing technologies target radionuclides. The technology can be applied to selected volatile organic compounds (VOCs) and pesticides.

Potential applications for the technology include metals recovery, organic and inorganic contaminant extraction from coarse-grained soils, and possibly radioactive contaminant extraction. In general, soil washing is most effective on coarse sand and reactive contaminants. Soils containing large amounts of clay and silt typically do not respond well to soil washing, especially if it is applied as a stand-alone technology.

Advantages of soil washing include a closed treatment system that permits control of ambient environmental conditions; potential significant volume reduction of the contaminant mass (depending on soil characteristics); wide application to varied waste groups; technology mobility (hazardous wastes remain on-site); and relatively low cost compared to other multicontaminant treatment technologies. Disadvantages include minimal reduction of contaminant toxicity and the use of potentially hazardous chemicals (e.g., chelating washing solutions). Also, soil washing requires significant materials handling and processing.

Technology Cost

According to a 1994 U.S. Environmental Protection Agency/Department of Defense (EPA/DOD) report, the average cost of soil washing (including excavation) is approximately \$130 to \$220 per metric ton (\$120 to \$220 per ton), depending on the target waste quantity and concentration of the contaminants (D10200H, p. 4–68). The estimated cost for soil washing, including all cost components, ranges from \$150 to \$250 per ton, when soil capacities of 25,000 to 200,000 tons (23,000 to 200,000 metric tons) are treated (D11242V, pp. 2.6–2.7).

There are 18 major cost components for a full-scale soil washing operation. These components include:

- Soil excavation
- Transporting excavated soil to the processing unit
- Stockpiling excavated soil temporarily
- Preventing contaminant releases to the environment during the first three steps

- Bulk soil treatment (such as screening, crushing, and physical/chemical characterization)
- Processing rocks, roots, debris, etc. that are unsuitable for soil washing
- Washwater supply facilities (such as storage tanks, pumps, piping, and controls)
- Supplemental supply facilities (such as storage tanks, pumps, piping, and controls)
- Soil washing system (possibly mixers, washers, screens, conveyors, etc.)
- Stockpiling, transporting, and depositing clean, washed soil product fraction temporarily
- Dirty washwater treatment process (usually a treatment train including clarifiers, chemical reactors, filter, carbon contractors, dewatering presses, tanks, etc.)
- Recycling or disposing of treated wastewater fraction
- Additional treatment and disposal of the dirty soil fraction
- Additional treatment and disposal of the water treatment sludge
- Permitting and legal services
- Engineering design
- Construction services
- Contingencies (D11242V, p. 3.25)

Information Sources

D10200H, U.S. EPA, October 1994

D11242V, WASTECH project (American Academy of Environmental Engineers [AAEE]), 1993

T0720

SoilClean Corporation

Electrochemical Soil Decontamination Process

Abstract

The electrochemical soil decontamination process is designed to treat organic compounds and heavy metals. It utilizes induced electrical currents to establish chemical, hydraulic, and electrical gradients designed to extract contaminants for soils. Treatment may be accomplished in situ or on site in lined cells.

According to the vendor, this commercially available technology can also enhance biological remediation.

This technology is designed to treat clays soils, nonstratified soils, soils containing more than 50% silt or clay, and soils with hydraulic conductivities of less than 0.001 cm/sec.

All information is from the vendor and has not been independently verified.

Technology Cost

No available information.

T0721

Soil Flushing — General

Abstract

Soil flushing is a commercially available, in situ technology for the treatment of soils contaminated with inorganic compounds including radioactive contaminants. The technology can also be used to treat volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs),

fuels, and pesticides. The addition of compatible surfactants may increase the effective solubility of some organic compounds; however, the flushing solution may alter the physical and chemical properties of the soil system. The technology offers the potential for recovery of metals and can mobilize a wide range of organic and inorganic contaminants from coarse-grained soils.

Low-permeability soils are difficult to treat with soil flushing. Surfactants can adhere to soil and reduce effective soil porosity. Reactions of flushing fluids with soil can reduce contaminant mobility.

The potential of washing the contaminant beyond the capture zone and the introduction of surfactants to the subsurface may cause problems. The technology should be used only where flushed contaminants and soil flushing fluid can be contained and recaptured.

Technology Cost
No available information.

T0722

Soil Safe, Inc.

Soil Recycling

Abstract
Soil Safe's commercially available soil recycling is an ex situ stabilization technology that binds petroleum hydrocarbon contaminants in soil through encapsulation into a soil cement sub-base material. According to the vendor, the soil cement material can then be used in the construction of roads, parking lots, dikes, berms, and caps/liners for landfills. According to the vendor, the technology can be implemented at either the client's facilities or its own facilities in Baltimore, Maryland, Savannah, Georgia, and Salem, New Jersey. The vendor claims that the technology can recycle petroleum-contaminated soils, sludges, coal tar, creosote, metals-contaminated soil, and various industrial wastes.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0723

Soil Technology, Inc.

Remediation Technologies Using Electrolytically Produced Water

Abstract
Soil Technology, Inc., has developed remediation technologies based on electrolytically produced water, which is its term for water that has been electrolytically processed to adjust its pH and reduction and oxidation potential. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0724

Soil Technology, Inc.

Soil Washing Treatability Study Unit

Abstract

Soil Technology, Inc., developed a bench-scale soil washer for use in treatability studies and uses it for custom testing to select full-scale soil washing remediation options. Soil washing is an ex situ technology. It is used to eliminate contamination in certain fractions of the soil, thereby reducing the total volume of soil that requires disposal as hazardous wastes. Soil contaminants tend to be associated with the fines and organic portions of soil. Soil washing is used to wash contaminants and fines from the gravel and sand portions, effectively separating the contaminated fines and water from the clean portion of the soil.

This treatability testing technology is commercially available. Soil Technology, Inc., was founded in 1990 and is an environmental geotechnical laboratory that assists customers in determining the best course of action for cleanup using soil washing.

All determinations of the appropriateness of soil washing should be made on a soil-specific basis. All information reported here is from the vendor and has not been independently verified.

See also Soil/Sediment Washing—General (T0719).

Technology Cost

At a salvage yard in Anchorage, Alaska, the cost of treating 250 kg of lead- and polychlorinated biphenyl–contaminated soil was $22,000. At a underground storage tank site at the Boston Central Arterial, 10 kg of soil contaminated with total petroleum hydrocarbon was treated at a cost of $45 per ton (D10328W, pp. 8–16).

Information Source

D10328W, VISITT 4.0, 1995

T0725

Solidification and Immobilization of Radioactive Wastes in Cement — General

Abstract

Solidification and immobilization of radioactive wastes, both solid and liquid, has been performed by incorporating them into cement. A variety of ways have been used, including making grout and cement blocks. Raffinate (aqueous waste) from uranium recovery and equipment decontamination, spent ion exchange resins, and nitrate radioactive wastes have been tested. Much of the information on this technology represents the results of research and development projects, generally funded by government nuclear energy agencies, such as the U.S. Department of Energy. These projects generally are not actively marketed as commercial products.

Technology Cost

No available information.

T0726

Stabilization/Solidification — General

Abstract

Stabilization/solidification is a proven technology for the in situ or ex situ treatment of certain hazardous wastes. It uses additives or processes to physically and/or chemically immobilize

the hazardous constituents in contaminated soils, sludges, sediments, or even liquid wastes. The objective of solidification/stabilization is to prevent the migration of contaminants into the environment by forming a solid mass.

By addition of certain chemicals reagents and rigorous mixing, the waste is fixed or stabilized. Contaminant mobility is reduced through the binding of contaminants within a solid matrix, which reduces permeability and the amount of surface area available for the release of toxic components.

This type of technology differs from most other remediation technologies is that the goal is to trap and immobilize contaminants within the existing medium, rather than trying to remove them via chemical or physical treatments.

Stabilization/solidification technologies are best suited for inorganics, including radionuclides. In theory, almost any waste can be solidified and/or stabilized. It can be used for base-, neutral-, or acid-extractable organics of high molecular weight. Stabilization/solidification technologies have been used to effectively treat refinery wastes, wood treating wastes, heavy metals, oil and grease, polychlorinated biphenyls (PCBs), plating wastes, and chlorinated and nitrated hydrocarbons.

According to the vendors, stabilization/solidification:

- Improves the handling and physical characteristics of the wastes (e.g., sludges are processed into solids).
- Reduces transfer or loss of contained pollutants by decreasing the available surface area.
- Reduces contaminant solubilities, generally by chemical changes.
- Can further treat residues from physical/chemical, biological, or incineration technologies.

The four major types of stabilization/solidification technologies included in the RIMS library/database are:

Cement-Based Stabilization/Solidification—General (T0149)
Pozzolanic Stabilization/Solidification—General (T0616)
Thermoplastic Stabilization/Solidification—General (T0801)
Polymer Stabilization/Solidification—General (T0615)

Technology Cost

The costs associated with stabilization/solidification (S/S) technologies have generally been considered low compared with those for other treatment techniques. The reasons for this are the availability of rather cheap raw materials (e.g., fly ash, cements, lime) used in the more popular processes, simple processing requirements, and the use of readily available equipment from the concrete and related construction industries (D150141, p. 7.99).

Organic S/S (use of thermoplastics or polymers) is often more expensive than other S/S methods. The urea formaldehyde and bitumen processes are likely the least expensive of this type but are still usually more costly than the more common inorganic processes. The waste often requires more pretreatment, and processing can be more difficult because of the higher temperatures and specialized equipment involved (D150141, p. 7.89).

It would be impossible to provide a standard cost for S/S. One study by the IIT Research Institute stated that the costs generally range between \$30 and \$200 per ton (D141468, p. 99). Reports from vendors usually do not define specific costs, but those given generally fall into the above price range. U.S. Environmental Protection Agency (EPA) studies have concluded with the same general price estimate. The final costs are highly dependent upon site-specific conditions. Contributing factors to the final cost include the waste characteristics, such as its physical form and chemical makeup, the amount of pretreatment required, transportation of raw materials to the site and treated materials from the site, the type of S/S process used (cements, fly ash, and such are cheaper raw materials than polyolefins and similar materials), and other random factors such as health and safety requirements and regulatory factors (D150141, p. 7.100). Other potential cost factors include the degree of homogeneity of soil, the presence of debris, and the amount of excess moisture in the soil (D16486X, p. 53).

Information Sources

D141468, IIT Research Institute, 1990

D150141, U.S. EPA, 1989

D16486X, U.S. EPA, 1997

T0727

Soliditech, Inc.

Soliditech Solidification and Stabilization Process

Abstract

Soliditech, Inc., has developed an ex situ solidification and stabilization process that immobilizes organic, metal, and inorganic contaminants in soils and sludges using cementlike binding materials and other chemicals. The treated waste is a solidified mass with significant unconfined compressive strengths (UCS), high stability, and a rigid texture similar to that of concrete.

The Soliditech process has been demonstrated in the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) program. Soliditech officially dissolved in 1995. The French group that owned Soliditech and held the patent for the solidification/stabilization process returned to France. The technology's commercial availability and licensing opportunities are unknown. An American law firm representing Soliditech is investigating these matters.

In EPA SITE demonstration of the Soliditech process, the solidified waste increased in volume by an average of 22% (D141413, p. 113).

The Soliditech reagent mix contains aluminum, barium, calcium, chromium, copper, lead, nickel, and sodium. The reagent mix may increase the concentrations of these metals in the final solidified product. The temperature of the treated waste should remain above freezing. The process is generally limited to wastes with pHs between 2 and 12. Wastes with pHs below 2 and above 12 require neutralization before treatment. If the treated material is not adequately mixed, unmixed clumps of waste material will appear in the solidified product. The long-term stability of the solidified product is unknown.

Technology Cost

Based on the U.S. EPA's SITE demonstration in 1988, the cost of treating 5000 yd^3 of contaminated waste using a 10-yd^3 mixer was estimated to be \$152/yd^3. Labor and supplies were the biggest cost factors, accounting for a cumulative 74% of the total cost (D213241, p. 21). A breakdown of this economic analysis is shown in Table 1.

The Soliditech solidification and stabilization process was used to treat 3000 drums of sand, top soil, clay, and rock from contaminated oilfields in Odessa, Texas. According to the vendor, the 3.5-week-long project cost \$850 per day (D213241, p. 49).

According to the vendor, the capital costs for a Soliditech mixer is \$65,000 (D213241, p. 22).

Information Source

D213241, U.S. EPA, 1990

TABLE 1 Itemized Costs Used for Economic Analysis of SITE Demonstration

Expense	Cost (in dollars)
Site preparation	25,000
Permitting/regulatory	10,000
Capital and ancillary equipment	11,417
Auxiliary equipment	63,060
Startup (mobilization and analysis)	21,000
Labor (9 people)	250,900
Supplies and consumables	313,910
Utilities	8,645
Effluent treatment and disposal	6,500
Residuals and waste shipping	0
Analytical	32,500
Facility modifications/repair/replacement	1,775
Site demobilization	15,000
Total	763,047

Source: From D213241.

T0728

Solox

Hybrid Solar/Electric Ultraviolet Oxidation System

Abstract
Solox has designed a hybrid solar/electric ultraviolet (UV) oxidation system for remediating organic contaminants in water. While the bench-scale system of this technology worked, according to the vendor, it has not been tested yet at field scale and is not commercially available. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0729

Solucorp Industries, Ltd.

Mercon

Abstract
Mercon™ is a patented liquid mercury vapor suppressant designed to stop and absorb mercury vapors. The chemical process used creates a mercuric salt or sulfide. The reagents react with the metal and absorb any ambient vapor. Mercon products have the ability to stop and absorb any methylation of mercury in water.

Mercon products are American Dental Association (ADA) approved and have been used in the dental, surgical, and medical laboratory environments for over a decade. The Mercon product line includes the following products: Mercondrum™, Mercongel™, Merconvap™,

TABLE 1 Mercon Price List

Product	Unit Size	Unit Case	Unit Cost (Dollars)	Product Weight (Pounds)
Merconvap	475 mL	6	21.50	2
Merconvap	1000 mL	6	28.50	2.4
Merconvap	22 liters	1	543.50	55
Merconvap	54 gal	1	3400.00	500
Mercontainer	455 mL	6	18.73	< 1
Merconspray	250 mL	6	16.76	2
Mercon Drum Kit	—	2	242.70	18
Mercongel	1000 mL	4	29.33	2.4
Merconwash	1000 mL	6	26.30	2.4
Merconsponge	—	6	16.28	< 1
Merconwipes	160 T[a]	6	24.90	1.25
Mercon Kit I	—	1	175.00	6.25
Mercon Kit II	—	1	160.00	7.75
Mercon Kit III	—	1	100.00	4.50

Source: From D15421C.
[a] T, towelettes that are precharged with Merconvap concentrate.

Merconkit™, Merconspray™, Mercontray™, Merconsponge™, Merconvap™ Industrial 22-Liter Drum, Merconwash™, Merconwipes™, and Mercontainers™.

Mercon is currently commercially available.

The Mercon product is not effective in soils. Another product, Quicksilver, has been developed to treat soils and sludges.

Technology Cost

Mercon products are currently used in commercial and industrial maintenance and remediation. Table 1 presents a price list for Mercon products (D15421C).

Information Source

D15421C, vendor literature

T0730

Solucorp Industries, Ltd.

Molecular Bonding System

Abstract

Solucorp Industries' molecular bonding system (MBS)™ is a patented process that stabilizes heavy metals. The technology uses proprietary mixtures of nonhazardous chemicals to convert heavy-metal contaminants from existing reactive/leachable forms (usually oxides) into stable, insoluble, metal–sulfide compounds. The vendor states that MBS is a mobile technology that quickly treats large volumes of waste on site.

The vendor states that MBS stabilizes heavy metals in soil, sludges, slag, ash, baghouse dust, and sediment. Among the heavy metals treatable by the MBS process are arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc. MBS technology is applicable in the following industries: primary and secondary smelters, battery manufacturers and recyclers, ferrous and nonferrous foundries, municipal solid waste incinerators, auto and metal scrap recyclers, electronic manufacturers, electroplaters, ceramic product manufacturers, and mineral refiners and processors.

According to the developer, the technology also has these advantages:

- Stabilizes Resource Conservation and Recovery Act (RCRA) heavy metals and most constituent metals.
- Treats multiple metals concurrently.
- Is not pH sensitive.
- Contributes less than 2% of the volume to the processed waste.
- Can be applied by in situ or ex situ techniques.

The MBS process is designed to reduce leachable concentrations from soils or solid waste. Certain metals present in their reduced form may require treatment with an oxidizing agent to improve treatment effectiveness. Materials with high chlorine content (in excess of 15 to 20%) cannot be effectively treated with this technology.

Technology Cost

According to the vendor, in the United States the typical cost for the disposal of a hazardous heavy-metal waste ranges from $175 to $240 per ton, and the typical waste management cost is approximately $275 per ton. According to Solucorp Industries, an in-line MBS would save a manufacturer up to $150 or more per ton of waste treated (D15307B, p. 1).

In 1997, MBS technology was demonstrated for the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) program at the Midvale Slag Superfund site in Utah. For this demonstration, an estimate was prepared of the total costs to treat the approximately 2 million tons of waste at the site. This estimate was based on a full-scale facility capable of treating 10,000 tons per day. Based on a scale-up from the demonstration, and on information supplied by the vendor, costs were estimated to be $16 per ton (D176710, p. 2).

Table 1 shows the vendor's cost comparison between the molecular bonding system technology and hazardous waste land filling. The data compares stabilization costs with transportation and disposal costs (D15306A, p. 3).

TABLE 1 Comparison of MBS versus Hazardous Landfill

Cost Element	MBS	Hazardous Waste Landfill	Variance
Stabilization cost (10,000 tons processed @ $35/ton)	$350,000	0	($350,000)
Transportation and disposal costs			
Total product weight	10,200	10,000	(200 tons)
Transportation and disposal (T&D)	$50/ton	$150/ton	$100/ton
Total T&D cost	$510,000	$1,500,000	$990,000
Total product and disposal cost	$860,000	$1,500,000	$640,000 (42.7%)

Source: Adapted from D15306A, p. 3.

Information Sources

D15306A, Solucorp, 1996
D15307B, Solucorp, 1996
D176710, U.S. EPA, 1997 web page

T0731

Solvay Interox, Inc.

ENVIROFirst Granules

Abstract

ENVIROFirst™ granules are a solid, dry, dust-free form of hydrogen peroxide (H_2O_2) used for treatment of contaminated liquids such as municipal sewage sludge or wastewater ponds or lagoons. It can also be used in odor control applications. During the chemical breakdown of the hydrogen peroxide, oxygen is released, which can then combine with many types of organic and inorganic contaminants, converting them to nonhazardous forms.

ENVIROFirst granules are uniform spherical granules that flow freely without creating dust. A unique manufacturing process keeps their moisture content below 0.1%, and therefore the granules can remain stable over long periods of time. They contain 13% available oxygen, which is equivalent to 27% hydrogen peroxide, and they decompose to oxygen, water, and sodium carbonate.

All information was provided by the vendor and has not been independently verified.

This technology does not handle metals.

Technology Cost

No available information.

T0732

Solvent Extraction — General

Abstract

Solvent extraction is a primarily ex situ separation and concentration technology in which a nonaqueous liquid solvent is used to remove organic and/or inorganic contaminants from wastes, soils, sediments, sludges, or water. The technology produces a treated fraction and a concentrated contaminated fraction that requires further treatment to recover, destroy, or immobilize the contaminants. It may concentrate contaminants by a factor as high as 10,000 to 1, thereby reducing the volume of material requiring further treatment.

Commonly used solvents include liquid carbon dioxide, propane, butane, light oil, triethylamine, acetone, methanol, hexane, dimethyl ether, crude oil, benzene, isopropyl ether, toluene, tricresyl phosphate, methyl isobutyl ketone, methyl chloride, and butyl acetate. In addition to remediation uses, solvent extraction has been applied in a variety of industries, including food processing, pharmaceuticals, fine chemicals, and mining and minerals processing.

There are many solvent extraction technologies included in the RIMS library/database. Solvent extraction technologies in RIMS that are currently commercially available include Biotherm, L.L.C., Biotherm Process (Second-Generation Carver-Greenfield Process) (T0034); EM&C Engineering Associates Extra Pure (T0244); Envirogen, Inc., Solid Organic Phase Extraction (SoPE) (T0266); Integrated Chemistries, Inc., Capsur (T0417); Integrated Chemistries, Inc., Pentagone (T0419); Metcalf & Eddy, Inc., ORG-X (T0516); Sanexen Environmental Services, Inc., Decontaksolv (T0685); and SRE, Inc., Solv-ex Basic Extractive Sludge Treatment (B.E.S.T®) Process (T0739).

Most solvent extraction technologies are not particularly effective for the removal of inorganic contaminants such as heavy metals. They may also have difficulty removing hydrophilic and high-molecular-weight organic compounds. High concentrations of organic compounds in the feed can reduce extraction efficiency and processing rates. Extraction efficiencies and processing rates are lower when emulsifiers and water-soluble detergents are in the feed.

All solvent extraction technologies use flammable organic extraction fluids that present potential fire and explosion hazards. Several of the extraction fluids include volatile or semivolatile compounds, which can create explosive vapor mixtures. A number of the extraction fluids contain toxic organic compounds; therefore, process designs must minimize or eliminate personnel exposure to these compounds.

Technology Cost

Unit cost data from various vendors of the solvent extraction technology is shown in Table 1. Estimates of unit costs of the systems ranged from $95 to $700/ton. This estimate includes the cost of disposal and destruction or treatment of all residue, analyses associated with system operations, and mobilization and demobilization. According to vendors, costs can vary substantially depending on the contaminant type and concentration, the media, and the quantity of material to be treated (D11243W, p. 5.3).

The U.S. Environmental Protection Agency (EPA) has published detailed cost estimates for the CF systems process and the Carver-Greenfield process, which include technology-specific costs and a breakdown of site-specific costs. In estimating costs for the CF Systems Process, the U.S. EPA postulated the following scenarios:

TABLE 1 Cost Comparison of Commercially Available Solvent Extraction Technologies

Process	Quantity $/tonne ($/ton)	Site Preparation Included	Disposal/ Destruction of Residues	Quoted Costs $/ tonne ($/ton)
B.E.S.T.	18,000 (20,000)	No	Yes	165 (150)
CF Systems	>57,000 (>63,000)	Yes	Yes	110–550 (100–500)
Carver-Greenfield	21,000 (23,000)	Yes	Yes	129–576 (117–523)
Extraksol	910 (1,000)	No	Yes	771 (700)
LEEP	>40,000 (44,000)	Yes	Yes	105–330 (95–300)
NKD	18,000 (20,000)	No	Yes	138–330 (125–300)
S.R.U.	450 (500)	No	Yes	220–661 (200–600)

Source: D11243W, Donnelly, 1995.
Note: B.E.S.T, Basic Extractive Sludge Treatment Process.
LEEP, Low-energy extraction process.
NKD, NuKEM development.
S.R.U., soil restoration unit.

- A base case treating 880,000 ton of sediments contaminated with polychlorinated biphenyls (PCBs) in concentrations of 580 ppm at 500 ton/day over a 3.3-year period:
- A hot-spot cast treating 63,000 ton of sediments contaminated with PCBs in concentrations of 10,000 ppm at 100 ton/day over a one-year period:
- Analytical costs of \$500/ day in both of the above cases.

The estimated cost for the base case was \$148 ± 20% per ton of raw feed, including excavation and pre- and posttreatment costs, but excluding final contaminant destruction costs. Excavation and pre- and posttreatment costs were estimated to be 41% of the total costs. The estimated cost for the hot-spot case was \$447, from −30% to +50%, per ton of raw feed. Excavation and pre- and posttreatment costs were estimated to be 32% of the total costs (D11243W, pp. 5.3–5.4).

The EPA's estimate for the Carver-Greenfield process assumed treatment of 23,000 ton of drilling mud contaminate with petroleum wastes. The total cost estimate was \$523/wet ton, with \$221/ton allocated to technology costs. Site costs were estimated to be \$302/ton, including \$240/ton for incineration of contaminated residuals. This estimate did not include regulatory, permitting, and analytical costs because of their variability (D11243W, p. 5.4).

Information Source

D11243W, Donnelly, 1995

T0733

Sonotech, Inc.

Cello Pulse Combustion Burner System

Abstract

The Cello® pulse combustion burner system is an ex situ technology for the enhancement of combustion devices. Cello pulse combustion can be incorporated into the construction of most new combustion devices or can be retrofit to most existing incinerators, boilers, and dryers. The system can be used to treat any material typically treated in a conventional incinerator, including soils, sludges, medical wastes, and liquids contaminated with volatile organic compounds (VOCs) or semivolatile organic compounds (SVOCs). The Cello system has been installed in commercial systems and is commercially available.

The technology can be tuned to induce large-amplitude sonic pulsations inside combustion process units such as boilers and incinerators. These pulsations increase heat release, mixing, and mass-transfer rates in the combustion process, resulting in faster and more complete combustion.

The vendor claims that pulse combustion technology has the following advantages over conventional, nonpulsating incineration:

- Higher incinerator capacity
- Lower carbon monoxide, soot, and nitrogen oxide emissions
- Lower combustion air requirements
- Lower energy requirements
- Reduced severity of transient puffs
- Reduced incineration system capital and operating costs
- Increased rate of incineration
- Reduced operating costs

- Technology can be applied to new or existing combustion systems
- Increased efficiency and more complete combustion

The Sonotech Cello pulse combustion system has the same limitations as a nonpulsating burner attached to a combustion device. Preliminary testing of the Sonotech system showed that in order to prevent slag formation, the temperature of the rotary kiln gas should not exceed 1700°F. The system produces considerable noise, which may be controlled by sound insulation. The Sonotech system uses resonant frequency of the incinerator to create pulsations. In an older incinerator, if the sound energy is not properly applied, the Sonotech system could cause structural problems.

Technology Cost

The estimated costs for equipment and installation of a full-scale system range from $65,000 to $75,000. According to one source, the annual cost of operation and maintenance was estimated to be $2500 (D11659G, p. 6). Another source estimated that the average annual operating cost of the Cello technology was $18,000 based on 1995 dollars (D14360C). These estimates are based on information compiled during the Superfund Innovative Technology Evaluation (SITE) demonstration in Jefferson, Arkansas (Case Study 1) and information supplied by the vendor. Estimated uncertainties are from +50% to −30% of actual costs. The total costs for the useful life of the equipment estimated at that time were $53,900. These estimates were based on the following assumptions:

- Pulse combustion burner equipment is retrofit to an existing incinerator by Sonotech personnel; the existing incinerator is located 500 miles away from the Sonotech facility, requiring that the combustion unit be transported 500 miles.

TABLE 1 Cost Associated with the Sonotech Cello Pulse Combustion Technology in March 1995 Dollars

Cost Category	Expenses[a]
Site preparation	$0
Permitting and regulatory costs	1,000
Mobilization and startup	13,100
Equipment[b]	36,000
Labor	0
Supplies	0
Utilities	0
Effluent treatment and disposal	0
Residual waste shipping and handling	0
Analytical services	0
Equipment maintenance	3,800
Demobilization	0
Total costs for the useful life of the equipment	$53,900
Average annual operating costs	$18,000

Source: Adapted from D14360C, pp. 31–32.

[a] All costs are rounded to the nearest $100.

[b] Based on a capital equipment base cost of $60,000; equipment has an estimated operational life of 3 to 5 years and no salvage value. Costs adjusted for depreciation.

- System is configured for an incinerator that has a feed rate of 2 tons per hour and operates at 30 million British thermal units per hour (Btu/hr).
- System increases the waste feed rate by 15%.
- System is operated 24 hr a day, 7 days per week, with an online operating efficiency of 80%.
- System operates automatically, requiring no additional labor efforts.
- Medium to be treated consists of soil contaminated with naphthalene at 10,000 mg/kg and benzene at 30,000 mg/kg.
- No additional air monitoring is necessary, and the system meets treatment goals for the soil (D14360C, pp. 29–30).

A breakdown of the estimated costs is provided in Table 1.

Information Sources

D14360C, U.S. EPA, 1996
D11659G, U.S. EPA, 1995

T0734

Sonsub International

Cryogenic Retrieval

Abstract
Cryogenic retrieval is an in situ technology for removal of buried radioactive waste. This technology involves ground freezing and remote removal of a soil and waste mixture. Cryogenic retrieval may reduce risk to workers and protect the environment from airborne and liquid contaminants during actual waste cleanup projects. The cryogenic retrieval technology was adapted from remote retrieval techniques used by Sonsub at Kerr Hollow Quarry, a hazardous waste site at the U.S. Department of Energy's (DOE) Oak Ridge facility.

This technology is currently commercially available.

The major technical challenges for this technology are developing a method for placement of freeze pipes in all types of soil and waste, conservation of liquid nitrogen used to freeze soil and waste, dispersion of water evenly throughout the soil and waste matrix, reduction of secondary waste created by the freeze pipes, selecting or developing more productive tools for the removal and handling of frozen waste, and improving methods for the measurement of thermal characteristics and for the detection of moisture migration.

Technology Cost
Initial investment for the Idaho National Engineering Laboratory (INEL) Cols Test Pit demonstration was $2.3 million (1996 dollars). An estimated cost of $1250 (1996 dollars) per cubic yard of frozen material extracted is expected for large-scale, high-efficiency application of the technology (D15324C, p. 5).

Information Source

D15324C, http://sc94.ameslab.gov

T0735

Sound Remedial Technologies, Inc.

Hot Air Vapor Extraction System (HAVE)

Abstract

The Hot Air Vapor Extraction System™ (HAVE) is an ex situ commercial technology that uses a sequence of thermal, heap pile, and vapor extraction techniques to remove and destroy hydrocarbon contamination in soil. This technology is effective in cleaning soils contaminated with gasoline, diesel, heavy oil, and polycyclic aromatic hydrocarbons.

To use HAVE System technology, soil is staged into a pile that contains heating and vapor extracting ducts. A burner, fueled initially by natural gas or propane feeds hot air through the pile, volatilizing contaminants. The vapor extracting ducts conduct the contaminants back into the burner, where they undergo combustion, providing energy to continue the remediation process. A fabric cover placed over the pile prevents the contaminants from escaping into the atmosphere.

The HAVE System is a simple, effective, and low-cost technology that completely destroys the contaminants that it removes. However, variables such as pile temperature, soil characteristics, soil moisture, and porosity can negatively affect the performance of HAVE.

The vendor claims that over 40 projects have been successfully completed nationwide. All sites contained soils contaminated with hydrocarbons that were remediated to nondetectable levels.

Technology Cost

Costs are for a full-scale production HAVE System with a capacity of approximately 2000 yd^3 of soil per month. Project sizes range from a 750-yd^3 cleanup to a 9000-yd^3 cleanup.

Operating costs are most affected by the processing rate. Soil moisture content and soil treatment temperature are site-specific factors that also affect cost. The vendor claims operating efficiency (and therefore cost efficiency) accrues quickly after the HAVE System has been mobilized to a site and system setup has been established.

Costs shown in Table 1 include:

- Equipment
- Startup
- Labor
- Supply and consumables
- Utility
- Equipment repair and replacement

Information Source

D132478, Innovative Technology Summary Report, Sound Remedial Technologies, 1995

TABLE 1 HAVE System Cost Estimates in Dollars per Cubic Yard

Size of project	750 yd^3 18 days	1500 yd^3 33 days	3000 yd^3 2 months	9000 yd^3 5 months
Comparative operating efficiency	60%	70%	80%	95%
Total cost per cubic yard of soil treated	57.50	48.50	43.50	35.50

Source: Data extrapolated from vendor-supplied cost information (D132478, p. 17).

T0736

SOUND/epic

Dispersion by Chemical Reaction (DCR) Technology

Abstract

SOUND/epic (SOUND) owns the distribution rights in the United States to the dispersion by chemical reaction (DCR™) technology. The DCR process is a lime-based chemical stabilization process used to convert oily wastes into a solid, free-flowing, soil-like material. The technology has also been applied to soils contaminated with toxic heavy metals. SOUND has used the technology on full-scale remediation activities in the United States, and it is commercially available.

The vendor claims that the advantages of DCR technology include that it is less expensive than competing technologies. The volume increase associated with the technology is less than 10%, and the reagent usage rarely exceeds 20%. The vendor states that volatile organic compounds (VOCs) are reduced in concentration and the solubility of metal contaminants is lowered.

The U.S. Army Corps of Engineers concluded that unless the hydrophobic material can readily disperse into the organic phase, the DCR process is not effective in immobilizing organic compounds. Treatability studies may be required for each specific waste stream. Difficulty was encountered in processing solid asphalt tar.

Technology Cost

No available information.

T0737

Spar Aerospace, Ltd.

Light-Duty Utility Arm

Abstract

Spar Aerospace, Ltd. (Spar), has developed the light-duty utility arm (LDUA) for the U.S. Department of Energy (DOE). The LDUA is a remotely controlled manipulator designed for use in the extremely hazardous environments commonly found in underground storage tanks. The unit is designed to be an integrated mobile system that performs inspection, surveillance, waste analysis, and small-scale retrieval tasks in underground storage tanks.

The first LDUA was delivered to the DOE facility at Hanford, Washington, in April 1996. In all, four LDUAs have already been delivered or scheduled for deployment at DOE sites. The technology is commercially available.

The major handicap of the LDUA system in performing in situ waste analysis is its light payload capacity, which restricts the penetration of end effectors into the waste to a limited depth dependent on the hardness of the waste materials. To fully access all parts of some storage tanks, the unit may need to be inserted through several ports in a storage tank.

Technology Cost

In 1997, the U.S. DOE announced that the LDUA technology used in conjunction with the Houdini robot had successfully removed tank sludge from a gunite tank at the Oak Ridge DOE facility. According to the project manager, cleaning the radioactive wastes from one gunite tank was estimated to cost approximately $1 million. The project costs of remediating eight gunite tanks at the Oak Ridge facility, from initial surveys through ultimate disposal, are estimated to be $66 million (D18205I, pp. 2–3).

Information Source

D18205I, Neal, 1997

T0738

SpinTek Systems

SpinTek Membrane Filtration

Abstract

SpinTek™ is a centrifugal membrane filtration unit for the filtration and fractionation of high fouling and viscous feed solutions. This technology is applicable to oily water, latex, radioactive wastewater, metalworking waters, plating waters, and contaminated groundwater. SpinTek Systems holds numerous worldwide patents on the SpinTek technology as well as other filtration patents for the solvent extraction of copper. SpinTek is commercially available through multiple vendors.

The SpinTek technology involves membranes that are bonded to two sides of a disk. Multiple disks are mounted on a hollow shaft that rotates the membranes, and stationary turbulent promoters are mounted near the rotary membranes to create high shear and turbulence. Liquid waste is pumped into the system that hits the spinning disk and spreads across the membrane. Centrifugal force pulls the solid waste outward to the perimeter of the filter disks, where it is removed from the system. By pulling the solids outward, the centrifugal force keeps the filter clear so that the system can run continuously.

According to the vendor, a key advantage of the SpinTek system is that the membranes are less likely to foul compared to static membrane systems. This feature results in less downtime for the system. The system also allows continuous operation during changes in influent waste stream characteristics, eliminating downtime for flux recovery. In addition, SpinTek requires a relatively small area for operations. The vendor states that the system is ideal for operation in hostile environments, including high temperature, pH, radioactive waste, chemical solutions, and solvent solutions.

The SpinTek system does not destroy the wastes but rather separates and concentrates them. Thus, additional treatment technologies may be required. In addition, the vendor points out that the system is not for every application in that it is designed for tough applications where normal static membrane filtration works poorly or not at all.

Technology Cost

The U.S. Department of Energy (DOE) states that SpinTek's volume-reduction capabilities will lower the disposal costs for wastes from U.S. nuclear weapons facilities. The use of a SpinTek system at the DOE's Los Alamos National Laboratory (LANL) is expected to save the government $4 million (D199148, p. 1). According to 1992 vendor information, pricing for the SpinTek "ST-5" system begins at $25,000, depending on configuration (D17920Y, p. 2).

Information Sources

D17920Y, Membrane & Separation Technology News, 1992

D199148, U.S. DOE, 1999

T0739

SRE, Inc.

Solv-Ex

Abstract
Solv-Ex is a solvent extraction process designed to treat soils, dredged sludges, and emulsions containing volatile or semivolatile organic compounds (VOCs or SVOCs), oils, grease, and coal tar. It is a separation technology; no actual degradation of the contaminants occurs. The process was developed in 1990 for treatment of sludges from steel mills. It was pilot tested on steel mill sludges in 1991. The technology has not been demonstrated beyond a pilot scale.

The basic process involves three steps: a pretreatment solvent application, actual solvent extraction, and a final drying phase. Pretreatment is done to break the emulsions. The drying phase involves steam heating to recover residual solvent. In some cases a biofilter is used to further treat liquid effluents if present.

According to the vendor, the key advantage of the system is that it can deal with soils and sludges that are very wet.

By present regulations, all target compounds that exist at concentrations for which the U.S. Environmental Protection Agency (EPA) has already enforced a cleanup technology that will not be treated by this technology (e.g., PCBs at greater than 50 ppm). In addition, by company policy, wastestreams containing radioactive components will not be treated by this technology.

Technology Cost
The vendor estimates that a full-scale system designed to treat from 50 to 500 tons per day would have a treatment cost ranging from $50 to $80 per ton. The vendor also claims that this technology treats solids with high oil and water content for less than $40 per ton for recovery of clean oil and solids (D17050D). No information was available on capital cost for the full-scale system, and it should be noted that no full-scale application has been conducted (D148770, p. 2).

Information Sources

D148770, vendor literature
D17050D, vendor literature

T0740

Stablex Canada, Inc.

Stablex Process

Abstract
The Stablex process is an ex situ hazardous waste fixation and solidification technology. This technology uses laboratory analyses to select appropriate physical and chemical treatment steps, followed by stabilization and solidification to produce an environmentally secure, nonleachable material. The final Stablex material is placed in landfill cells as a slurry so that it forms a monolith within the cell.

The Stablex process is based on the patented Sealosafe process developed in England in the late 1970s. According to the vendor, this technology is currently commercially available.

The Stablex pore fluid, an inherent component of the material, shows some chemical characteristics of hazardous waste; however, the fluid is confined within the clay and does not affect its permeability.

Technology Cost

According to the vendor, pricing is relative to factors including the size of the job and the nature of the treatment as well as the financial arrangements, whether they be lump sum, cost plus, or other (personal communication: John T. Corcia, Stablex, 1997).

T0741

Stark Encapsulation, Inc.

METLCAP Chemical Cement

Abstract

METLCAP is a chemical cement that encapsulates, stabilizes, and solidifies hazardous heavy metals in solid form, in slurry form, or in solution. The cement is composed of magnesium oxychloride, which forms when magnesium chloride and magnesium oxide, with water, are mixed together with the metals. The hardened cement product is insoluble and itself becomes a usable resource as cement or as fill material. The METLCAP technology is applicable as an in situ or ex situ treatment or for high-pressure injection grouting and construction of slurry walls. Currently, the process is patented and commercially available from Stark Encapsulation, Inc.

The cement is effective in immobilizing six hazardous heavy metals but is less effective for barium and selenium.

Technology Cost

Costs for using this technology can range from \$30 to \$105 per ton (\$33 to 116 per metric ton) of treated material, plus freight, a laboratory fee of \$1000, and a one-time license fee of \$5000 to \$20,000.

The cost per ton depends on the percent, by weight, of metals in the material to be treated, as well as the quantity to be treated. Royalty fees decrease per ton when more waste is treated. License fees increase for a user with more waste to treat.

The reagents used for the METLCAP technology are readily available and fairly inexpensive, as magnesium chloride is a commercially available by-product from the production of potash (D12759N, p. 8).

Information Sources

D12759N, U.S. Patent 5,276,255

D12762I, Stark Encapsulation, 1996

Personal communication with J. Norman Stark, 10/24/96

T0742

Starmet Corporation

RocTec Stabilization

Abstract

RocTec™ stabilization is a process to transform incinerator ash and other materials into small briquettes, which are then sintered to increase their strength, make them leach resistant, and reduce their volume. A ceramic stabilization process, it is applicable for metal oxide matrices containing metals designated as toxic under the Resource Conservation and Recovery Act

TABLE 1 Comparison of Additive Quantities and Unit Cost

Parameter	RocTec	Cement	Polyethylene
Mass of additive per pound of ash (lb)	0.2	4.0	0.5
Cost per pound of additive ($/lb)	$0.10	$0.07	$0.50
Additive cost per pound of ash stabilized ($)	$0.02	$0.28	$0.25

Source: From D169497, William Quapp, 1997, p. 6.

(RCRA) and/or nuclear materials. It can be applied to several types of contaminated matrices including soil, sludge, and incinerator ash.

Wastes containing high levels of halogenated salts, zinc, lead, or mercury may pose problems for this technology due to volatilization and/or incomplete incorporation into the stabilized matrix.

Technology Cost

According to the developer, the reagents for the RocTec process cost less than $0.10/lb, as compared to $0.07/lb for cement and $0.50/lb for polyethylene. Table 1 shows the relative amounts of additive required for these methods of stabilization and the costs of each (D169497, p. 6).

Based on comparable processes in the ceramics industry, the total processing cost (including additives) of RocTec aggregate is expected to be less than $1.00/lb (D169497, p. 7). This estimated cost does not take into account costs related to disposal of the aggregate.

Information Source

D169497, William Quapp, 1997

T0743

Starmet Corporation

Ducrete Concrete

Abstract

Ducrete™ concrete is a material made of concrete and depleted uranium hexafluoride. Ducrete concrete uses aggregate manufactured from uranium oxide as the large aggregate in a concrete mixture. It is used for storage of radioactive waste such as spent fuel or high-level wastes. Ducrete concrete can also be used in other shielding applications such as temporary shielding in reactor facilities, low-level radioactive waste storage or disposal boxes, and for commercial food and medical irradiator applications. Ducrete concrete has a density three times that of conventional concrete, therefore reducing the wall thickness required to attenuate radiation (D202391, pp. 1, 2).

Bill Quapp, a consulting engineer at the Idaho National Engineering and Environmental Laboratory (INEEL), evaluated a depleted uranium rocklike aggregate as an ingredient in concrete, with the results being a much cheaper alternative to fabricating uranium metal casks. The initial proof of concept tests were carried out in 1993. Following these successful tests development efforts have focused on the manufacturing process. Patent protection is being obtained by the Lockheed Martin Idaho Technologies Company (LMIT) in the United States and elsewhere. LMIT continues its aggregate development efforts.

The technology has now been licensed to the private sector for further development and commercialization. Quapp left INEEL to form Teton Technologies, Inc. (TTI). TTI, with a Ducrete shielding license, formed a joint venture with Starmet Corporation (formerly Nuclear Metals, Inc.), a Massachusetts-based advanced metals technology company that will continue commercial-scale development of the process.

Using Ducrete shielding, containment of dangerous levels of radiation from spent fuel can be achieved with thinner shield walls and lower weight casks, making handling and transporting easier. According to the vendor, although the uranium itself is slightly radioactive, it contributes only a small amount to the materials that it is shielding. It works with the cement and sand to provide a more effective barrier to radiation than normal concrete or depleted uranium metal alone.

This technology is applicable only to radioactive material. It acts as radiation shielding only, it does not treat waste.

Technology Cost

The U.S. Department of Energy (DOE) found the cost to dispose of depleted uranium hexafluoride ranged from \$4 to \$12 billion. As an alternative to disposal, INEEL developed a concept of converting depleted uranium into an oxide aggregate material for use in cement. This cement material is known as Ducrete cement and is used as a shielding material (D202937, p. 1).

Information Source

D202937, U.S. Department of Energy, 1999

T0744

Startech Environmental Corporation

Plasma Waste Converter

Abstract

Startech Environmental Corporation's Plasma Waste Converter™ (PWC) is an ex situ, closed-loop elemental recycling system that converts wastes into useful commercial products. The technology is capable of processing hazardous and nonhazardous solid, liquid, and gaseous wastes (both organic and inorganic). The PWC uses a plasma system to induce molecular dissociation in the waste material, causing the material to dissociate into its corresponding elemental components. Depending on the wastes being processed, some of these components may be recovered. Recovered products may include metals, an obsidian-like inert silicate stone, and a clean synthetic fuel gas called plasma converted gas (PCG).

Startech PWC systems are applicable to manufacturing facilities, hospitals, process plants, military sites, and municipalities. Systems have been used in the field to treat chemical weapon and explosive simulants. In addition, the vendor claims that the technology has successfully treated metals, such as lead and barium, during testing. The technology is commercially available in the United States and overseas.

During a U.S. Department of Defense (DOD) demonstration of the PWC at Aberdeen Proving Ground, air leaked into the system. As a result, the PCG that was produced consisted of carbon dioxide and water, instead of carbon monoxide and hydrogen.

Technology Cost

The vendor states that the cost of using the PWC typically ranges from \$0.07 to \$0.10/lb. This cost range takes into account expenses associated with "labor, materials, utilities, consumables, and capital depreciation." Revenues from the possible sale of process by-products are not figured into this estimate (D22691P, p. 2–34). The vendor also claims that the modular construction method used to manufacture the PWC units lowers costs and makes it cost-effective to ship the units overseas (D22680M, p. 47).

According to the U.S. DOD, the capital costs for PWC are similar to the costs for conventional incineration methods (D213605, p. 242). In contrast, operation and maintenance (O&M) costs are believed to be 15 to 20% higher for PWC than for incineration. Insufficient data existed, however, to perform an in-depth comparison of total O&M costs for the two technologies (D22691P, p. 2–35).

Information Sources

D213605, Clean Water Report, 2000
D22680M, PRNewswire, 2001
D22691P, U.S. EPA, 2000

T0745

State University of New York, Oswego, Environmental Research Center

Electrochemical Peroxidation

Abstract

Electrochemical peroxidation (ECP) is a treatment technology that combines electricity, iron, and hydrogen peroxide to destroy organic contaminants in groundwater, surface water, leachate, and soils. A small electric current enhances remediation using a process similar to Fenton's reagent oxidation. Fenton's reagent is a combination of hydrogen peroxide and soluble iron salts and has been used extensively in water treatment and remediation applications.

The technology has been used during bench-scale experiments and field-scale demonstrations. The technology is available for licensing through SUNY, Oswego, and is commercially available through Environmental Oxidation Systems, L.L.C.

Researchers claim ECP has the following potential advantages:

- Destroys organic contaminants.
- Treats liquids or slurries.
- Is an in situ and ex situ treatment process.

In bench-scale tests, the process pH had a significant impact on treatment effectiveness. A reduced effectiveness has been observed for treatment of highly chlorinated polychlorinated biphenyls (PCBs) as compared with less chlorinated PCBs. Studies have shown that electrode spacing, frequency of polarity changes, number of electrodes, and other configuration changes affect the performance of ECP technology. In situ applications of this technology are most effective in a permeable substrate with elevated ferrous iron concentration, low pH, and anaerobic conditions.

Technology Cost

Estimated costs of ECP treatment range from \$0.20 to \$20 per 1000 gal of contaminated groundwater treated (D19128Q, p. 1; D19129R, p. 1). Costs will vary depending on the contaminant treated, solids percent of the influent, and other site-specific variables. Operational costs for a site contaminated with 10 to 25 parts per million (ppm) in total hydrocarbons [chiefly chlorinated hydrocarbons or benzene, toluene, ethylbenzene, and xylene (BTEX)] were estimated to be \$0.50 per 1000 gal of contaminated groundwater treated. This estimate does not include profit (D19413S).

Environmental Oxidation Systems, L.L.C., prepared cost estimates for a theoretical ECP system. The system was designed to treat water contaminated with 5000 parts per billion (ppb)

TABLE 1 Estimated Treatment Costs Using Electrochemical Peroxidation (ECP)

Cost Item	Costs of ECP at 10 gpm	Costs of ECP at 20 gpm
Monthly Costs		
Energy	\$522	\$688
Chemical	\$290	\$588
Maintenance	\$425	\$440
Total monthly costs	\$1,237	\$1,716
5-year cost estimate		
Equipment	\$24,600	\$24,600
Sum of monthly costs	\$74,220	\$102.960
Total costs for 5 years	\$98,820	\$127,560

Source: Adapted from D22705E.

of methyl tert-butyl ether (MTBE). The costs were estimated to be \$3.70 per 1000 gal of water treated in a 10-gal/min (gpm) system and \$2.39 per 1000 gal of water treated in a 20-gpm system (D22705E, p. 25). Table 1 displays the costs associated with this theoretical system.

After the pilot-scale demonstration at a former petroleum storage site in Saratoga Springs, New York. Environmental Oxidation Systems, L.L.C., estimated the cost of consumables used during an ECP application. Pretreatment with 93% sulfuric acid would cost approximately \$0.40 per 1000 gal of water treated. The hydrogen peroxide could be applied at a cost of \$0.37 per 1000 gal of water treated. The electricity required by the electrodes would cost approximately \$0.06 per 1000 gal of water treated (D22708H, p. 12).

Information Sources

D19128Q, SUNY Oswego web page, undated

D19129R, GNET, undated

D19413S, Scrudato, 1999 correspondence

D22705E, Aztech Technologies, Inc., undated

D22708H, Healy and Fina, undated

T0746

STC Remediation, Inc.

Solidification/Stabilization Technology

Abstract

The STC Remediation, Inc., technology is a commercially available, chemical treatment and solidification/stabilization process designed to reduce the mobility and leaching potential of organic and inorganic contaminants in soil, sludge, and wastewater. STC's proprietary silicate-mineral reagents bind contaminants within a layered alumino-silicate structure. The waste is then encapsulated in a concrete-like material, producing a high-strength, rocklike material. The reagents are chosen based on the chemical composition of the waste.

Many types of organic and inorganic wastes, including heavy metals, polycyclic aromatic hydrocarbons (PAHs), and aliphatic compounds, can be treated using this process. This technology is unable to treat low-molecular-weight organics such as alcohols, ketones, and glycols.

According to the vendor, the STC solidification/stabilization technology has several advantages:

- Uses reagents that can be applied dry or in slurry form using conventional construction equipment or specialized in situ mixing equipment.
- Reduces leachability through the chemical fixation of the organic component of the waste.
- Can result in a reduction in the volume of solid waste.
- Produces an encapsulated product with a theoretical, long-term durability.
- Able to treat a wide variety of hazardous soil, sludge, and wastewater.
- Is suitable for large sites because of the comparatively low cost of the reagents.
- Uses the equipment that is commonly available and can be obtained locally.

Solidification/stabilization technologies are not appropriate for wastes containing significant quantities of volatile contaminants that could be released during the excavation and materials handling steps. The technology usually requires that the contaminated material be excavated for effective mixing with the reagent; however, an in situ application has been demonstrated at a site with deep, subsurface contamination. Solidification/stabilization processes usually increase the volume of waste requiring disposal.

Technology Cost

The U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) report (D10246V, pp. 29–42) contains a detailed economic analysis intended to provide information that will allow a remedial project manager or facility manager to develop site-specific costs associated with the use of the STC immobilization technology. The reports estimated the costs of using the STC immobilization technology to treat 15,000 yd^3 of soil contaminated with organic and inorganic compounds. Variables in the analysis included use of two sizes of mixers (5 and 15 yd^3) and two different mixing times (0.5 and 1 hr per batch). The analysis resulted in costs ranging from \$190 to \$330/yd^3 of contaminated soil. The analysis broke the costs down into the following components:

- LBHIReagent cost: \$80 to \$153/yd^3, depending on organic content of the waste
- LBHIProcessing cost: \$40 to \$175/yd^3
- LBHILabor cost: 9 to 14% of the total cost
- LBHIAnalytical expenses: 4 to 12% of the total cost

The total treatment cost was estimated to range from \$2,843,534 to \$4,913,308. This estimate does not include off-site transport and disposal. Off-site disposal, if required, could significantly increase the cost of using this technology (D10246V, p. 5).

The cost of the reagent could be significantly lower at sites with levels of organic contamination below 500 parts per million (ppm) due to the fact that less reagent would be required to stabilize the waste (D10246V).

The technology was used to stabilize more than 100,000 yd^3 of soil contaminated with heavy metals, polychlorinated biphenyls (PCBs), and organic compounds at the Tacoma Historical Coal Gasification Superfund site in Tacoma, Washington. According to the vendor, the reagent costs for this demonstration were \$980,000. The cost of the excavation and material handling portions of the remediation is unavailable (D113382).

Between 1994 and 1995, STC Remediation, Inc., performed a full-scale remediation project at the Gould Superfund site in Portland, Oregon. Approximately 60,000 yd^3 of soil and debris at the battery recycling facility were contaminated with lead. The vendor states that the reagent costs were approximately \$28.00 per ton of waste (D113382, p. 8).

At a former lead smelting facility in Benicia, California, approximately 11,500 tons of lead-contaminated soil were treated and placed in an on-site repository. According to the vendor, the stabilization costs were $70 per tons of soil treated. The contracting and reagent costs for the project were $805,000 (D113382, p. 9).

Solidification/stabilization technology was used at an existing metal recycling facility in Sun Valley, California, to treat 20,000 tons if soil contaminated with lead and total petroleum hydrocarbons (TPH). The vendor stated that the treatment reagents and the on-site technical services for this project cost $9.00 per ton (D113382, p. 10).

At a TPH-contaminated site in Seattle, Washington, the technology was used to treat 5000 tons of contaminated soil. The vendor estimates that the total cost for this project was $500,000. STC Remediation, Inc.'s, supervision and reagent costs were $180,000 (D113382, p. 11).

Approximately 4000 tons of copper-contaminated soils from a former electroplating plant in City of Industry, California, were stabilized using the STC Remediation, Inc., technology. According to the vendor, the stabilization costs were $70 per ton of soil treated. Contracting and reagent costs were $37 per ton of soil treated (D113382, p. 12).

In 1990, 10,600 tons of soil contaminated with cadmium and lead from a former battery recycling facility in Savannah, Illinois, were treated with the STC Remediation, Inc., reagents. The vendor states that the reagents, on-site technical support personnel, and the on-site quality assurance personnel cost $51.00 per ton of soil treated (D113382, p. 13).

According to the vendor, the costs of reagents, on-site technical support personnel, and on-site quality assurance personnel were $60 per ton of soil treated at a former electroplating facility in McPherson, Kansas. The reagents were applied to 1500 yd^3 of chromium-contaminated soil (D113382, p. 15).

At the NcNeil Island Correctional Facility in McNeil Island, Washington, 150 yd^3 of soil contaminated with lead were stabilized. The vendor stated that the total project costs were $75 per ton of soil treated. The costs of reagents, on-site technical support personnel, and on-site quality assurance personnel were $45 per ton (D113382, p. 16).

Between 1986 and 1987, STC Remediation, Inc., treated 110,000 yd^3 of soil from a former steel manufacturing facility in Tempe, Arizona. The soil was contaminated with lead and cadmium. The company stated that the total treatment costs for the project were $7,500,000. Reagents, on-site technical support personnel, and on-site quality assurance personnel cost $25 per ton of soil treated (D113382, p. 17).

According to the vendor, the technology was used to remediate 2000 tons of hazardous waste from an oil refinery in Old Ocean, Texas, at the cost of $800,000. The vendor's supervision and reagent costs were $43,224 (D113382, p. 18).

At another oil refinery in Eldorado, Arkansas, the technology treated 30,000 yd^3 of impoundment sludge. STC Remediation, Inc., states that the reagent cost for this project was $8.00 per ton of treated waste (D113382, p. 19).

Information Sources

D10246V, U.S. EPA, 1994

D113382, STC Remediation, Inc., undated

T0747

SteamTech Environmental Services and Integrated Water Resources, Inc.

Steam-Enhanced Extraction (SEE)

Abstract

Steam-enhanced extraction (SEE) is a thermally enhanced, in situ, extraction technology that removes volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs),

including non-aqueous-phase liquids (NAPLs), from the subsurface. Injection wells force steam through soils and aquifer materials to volatilize organic compounds. Extraction wells are then used to capture and extract groundwater and hot vapors containing the volatilized contaminants. The vapors are condensed, contained, and treated at the surface. The SEE technology uses readily available components such as injection, extraction, and monitoring wells; manifold piping; vapor and liquid separators; water treatment systems; and gas emission control equipment.

Proof-of-concept studies, and pilot-scale and full-scale demonstrations, have been successfully completed for a variety of contaminants, and additional full-scale applications are planned. Berkeley Environmental Restoration Center is currently seeking commercial licensees for SEE. The technology is commercially available through SteamTech Environmental Services and Integrated Water Resources, Inc.

The process offers potential advantages over conventional pump-and-treat methods:

- Reduced volumes of contaminated fluid to be treated
- Shorter times for remediation
- Applicability to contaminants above and below the water table
- Potential for reuse of recovered contaminants

Limitations of the SEE technology include the following:

- Performs best in permeable soils and aquifers, where steam can effectively contact contaminants.
- Dense non-aqueous-phase liquids (DNAPLs) may be treated only in low concentrations, unless a barrier exists or can be created to prevent downward contaminant migration.
- Cannot be applied near the ground surface unless a cap or low-permeability barrier exists to maintain steam injection pressures.
- Treated soils can remain at elevated temperatures for months and even years after cleanup, which could affect site reuse plans.
- Labor-intensive and requires significant field expertise to implement.

Technology Cost

According to the Federal Remediation Technologies Roundtable, costs for stationary, in situ, steam flushing technologies range from \$50 to \$300/yd^3 of media to be treated. The most significant factors affecting the cost are the number of wells required per unit area, depth to contamination, soil permeability, and site geology (D198076, p. 2).

Although no specific cost information was available for using SEE alone, cost estimates are available for dynamic underground stripping (DUS). DUS is a technology developed jointly by researchers at the University of California at Berkeley (UCB) and U.S. Department of Energy's (DOE's) Lawrence Livermore National Laboratory (LLNL). The DUS technology combines SEE with direct electrical heating and underground imaging techniques to improve steam extraction performance in subsurface environments with contaminated, low-permeability clay layers. See the technology summary for DUS (T0748) for more information. Note that the DUS costs discussed below incorporate electrical heating and electrical resistance tomography (ERT) monitoring along with the SEE process; lower costs would be expected for applications of SEE alone.

Detailed costs for DUS technology were estimated for a shallow (less than 50-ft-deep) chlorinated solvent spill. The LLNL cost estimates assume that DUS is applied to 10,000-yd^3 cells and that the equipment is relocated to each cell location. Based on these assumptions, the total DUS implementation costs were less than first-year construction and operating costs for conventional

TABLE 1 Estimated Costs for Dynamic Underground Stripping

Site	Cost ($ per yard)
Complete cleanup of 20,000 to 40,000 yd^3	28
Pilot-scale treatability study using full-scale equipment	37
Sites larger than 40,000 yd^3	11–15
6-month cleanup of 29,000 yd^3	16
2-year cleanup of 29,000 yd^3	64

Source: From D114523.

groundwater pump-and-treat systems. Additional cost estimates from this study are displayed in Table 1.

These cost estimates are preliminary approximations for work within the DOE environment and are based on experience gained during the DUS demonstration at the LLNL gasoline spill site. Costs not specified in these estimates include disposal costs for boiler blowdown and equipment costs for off-gas treatment (D114523, pp. 10–12).

Information Sources

D114523, U.S. DOE, 1996

D118149, Bremser and Booth, 1996

D198076, Federal Remediation Technologies Roundtable, undated

T0748

SteamTech, Inc., and Integrated Water Technologies, Inc.

Dynamic Underground Stripping (DUS)

Abstract

Dynamic underground stripping (DUS) is a thermally enhanced in situ extraction technology that removes volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs), including non-aqueous-phase liquids (NAPLs), from groundwater and soils above and below the water table. DUS technology relies on three integrated technologies: (1) electrical heating of clay and other low-permeability soil layers to drive contaminants into more permeable soil zones, (2) steam injection/vacuum extraction to volatilize and extract contaminants from the soil, and (3) underground imaging using electrical resistance tomography (ERT) to monitor and control the process.

Although DUS has been successfully demonstrated in a full-scale cleanup, the U.S. Department of Energy (DOE) states that additional data on long-term routine operating experience with DUS are needed. In addition, demonstration results are needed for chlorinated solvents [including dense non-aqueous-phase liquids (DNAPLs)], mixed wastes, and fractured subsurface media. DUS technology is commercially available through Lawrence Livermore National Laboratory (LLNL) and the University of California at Berkeley, who are currently negotiating nonexclusive licenses with government and private parties.

Advantages over conventional pump-and-treat methods include reduced volumes of contaminated fluid to be treated, shorter times for remediation, applicability to contaminants above and below the water table, and potential for reuse of recovered contaminants.

Treatment of DNAPLs may be limited unless a barrier exists or can be created to prevent downward migration of contaminants during treatment. The DUS technology cannot be applied to contaminated soil near the surface unless a cap exists because steam injection pressures cannot be maintained. Treated soils can remain at elevated temperatures for months and even years after cleanup, which could affect site reuse plans.

Although DUS is extremely effective in the absence of liquids (i.e., in soils above the water table), it usually is not cost-effective compared to alternative technologies in these instances. The DUS technology is labor-intensive, requiring significant field expertise to implement. It is best applied to sites with contaminants above and below the water table (i.e., groundwater and soil contamination) and complex sites that are very difficult to clean up.

Technology Cost

The average costs for a DUS remediation application is approximately \$50/yd^3. According to the developer, energy costs are approximately \$2/yd^3 for steam and approximately \$5/yd^3 for electric applications. The system becomes more cost effective at larger sites (D11318Y, p. 3; D19516Y, p. 19; D20105O, p. 1).

The total cost of the LLNL gasoline spill site demonstration was \$10.4 million, or \$104/yd^3 (assuming a total cleanup volume of 100,000 yd^3 of soil and 1993 dollars). This figure includes costs for research and development. The U.S. DOE believes that with the benefits of lessons learned and the elimination of research activities, remediation costs for the LLNL gasoline spill site would be 40% lower than the demonstration costs (see Case Study 1, D168698, pp. E1–E3; D19319V, pp. 17–20; D20102L, p. 2).

Combining DUS with hydrous pyrolysis/oxidation (HPO) technology eliminates treatment, handling, and disposal costs associated with DUS effluent by destroying the contamination in the ground. The vendor estimates that the average costs are between \$15 and \$35/yd^3. The cost to remediate the Visalia, California, site will be less than \$20,000,000. This estimate includes a 5-year postremediation monitoring program (D18785D, p. 39; D20039V, p. 2; D19516Y, p. 19; D200986, p. 3; D20027R, p. 2).

LLNL researchers prepared a DUS cost estimate for a shallow chlorinated solvent spill at the DOE Pinellas facility. They estimated average cleanup costs of \$65/yd^3 of treated soil (D168698, pp. E1–E3).

Based on experience at the LLNL gasoline spill site demonstration, DOE estimated the costs for a shallow (less than 50 ft deep) chlorinated solvent spill. The cost estimates assume successive application of DUS to 10,000-yd^3 cells, relocating equipment to each cell location. Key results are:

- Complete cleanup of the 20,000- to 40,000-yd^3 site would cost approximately \$28/yd^3.
- A pilot treatability study, using full-scale equipment, would cost \$37/yd^3.
- Larger sites could cost \$11 to \$15/yd^3.
- Total implementation costs were less than first-year construction and operating costs for conventional groundwater pump and treat.
- Costs depend on length of time for cleanup, ranging from \$16/yd^3 for a 6-month cleanup to \$64/yd^3 for a 2-year cleanup (assuming 29,000 yd^3 of soil) (D168698, p. 10).

These cost estimates are preliminary approximations for work within the DOE environment. Costs not specified in these estimates include disposal costs for boiler blowdown and equipment costs for off-gas treatment; more detailed cost information may be found in D168698 (pp. 10–12).

TABLE 1 Costs for Dynamic Underground Stripping (DUS), Pump and Treat with Soil Vapor Extraction (SVE), and Soil Excavation[a]

	DUS "New"[b]	DUS[c]	Pump and Treat with SVE	Soil Excavation[d]
Time for cleanup	6 months	9 months	30 years	1 year
Cost of cleanup	$6 million	$10–$11 million	$30 million	$25 million

Source: From D114523, p. 12.
[a]For cleanup of gasoline spill site at Lawrence Livermore National Laboratories.
[b]Assumes 40% cost reduction from use of lessons learned and elimination of research activities (see Appendix E, D114523, p. E3).
[c]Cost of DUS demonstration at Lawrence Livermore National Laboratories site.
[d]Includes relocation of underground utilities.

TABLE 2 Cost Comparison for Dynamic Underground Stripping (DUS) and Pump and Treat with Soil Vapor Extraction (SVE)

Cost Parameters[a]	Dynamic Underground Stripping	Pump and Treat with Soil Vapor Extraction
Site-specific capital equipment[b]	$703,800	—
Reusable capital equipment amortization[c]	$112,200	—
Capital equipment amortization[d]	—	$776,000
Operation and maintenance	$274,800	$888,500
Total	$1,090,800	$1,664,500
Unit cost per cubic yard	$38	$57
Cubic yards remediated	29,000	29,000
Time to cleanup	6 months	5 years

Source: From D118149, pp. 39, 41.
[a]Present value (1996) computation with no inflation and a real discount rate from Office of Management and Budget Circular No. A-94, February 1996 (see D118149, p. 35).
[b]Initial capital costs not transferable to any subsequent project (well drilling, mobilization, etc.), not amortized over project life.
[c]Capital costs for equipment to be used at other, future remediation locations, amortized over a 5-year operating lifetime.
[d]Capital costs amortized over the life of the project.

DOE also compared cleanup costs and times for DUS and conventional groundwater pump and treat with soil vapor extraction and soil excavation (D168698, p.12). Table 1 summarizes the results of this comparison.

LANL also compared DUS costs to conventional pump and treat with soil vapor extraction; Table 2 summarizes the results. The LANL estimate was prepared for a hypothetical site with deep vadose zone (soils above a 100-ft-deep water table) and groundwater contamination. The contamination source is assumed to be a tank buried 20 ft deep that is leaking SVOCs. Contaminants have migrated below the tank and penetrated a 20-ft clay layer 40 ft below the tank to contaminate groundwater. The total volume of SVOC-contaminated soil is 29,000 yd^3 (D118149, pp. 8, 9). Figure 4 in D118149 (p. 10) pictures this scenario. Cost estimate details may be found in the Appendix to D118149 (Scenario 4).

Information Sources

D11318Y, U.S. DOE, undated

D118149, Bremser and Booth, 1996
D168698, U.S. DOE, 1995
D18785D, NATO, 1998
D19319V, U.S. DOE, undated
D19516Y, Industrial Wastewater, 1999
D20027R, vendor literature, undated
D20039V, vendor literature, undated
D200986, U.S. DOE, undated
D20102L, U.S. DOE, undated
D20105O, U.S. DOE, 1995

T0749

SteamTech, Inc., and Integrated Water Technologies, Inc.

In Situ Hydrous Pyrolysis/Oxidation (HPO)

Abstract
Hydrous pyrolysis/oxidation (HPO) is an in situ thermal remediation technology that uses hot, oxygenated groundwater to mineralize organic compounds such as chlorinated solvents and refractory hydrocarbons such as creosote. HPO works on the principle that in the presence of oxidants (oxygenated water or soil minerals), organic chlorinated compounds will readily oxidize to carbon dioxide and chlorine ions when heated to the boiling point of water. HPO is a rapid, in situ remediation technique that destroys subsurface contaminants, such as dense non-aqueous-phase liquids (DNAPLs) and dissolved organic components, without the need for extraction.

HPO uses dynamic underground stripping (DUS) technology to inject steam and oxygen into the subsurface. When injection stops, the steam condenses, and contaminated groundwater returns to the heated zone. Chlorinated contaminants in the groundwater mix with the oxygen and condensate and, with the presence of heat, rapidly oxidize into carbon dioxide and chloride. HPO is able to destroy the residual DNAPL components not readily removed by the DUS process.

HPO was developed by Lawrence Livermore National Laboratory (LLNL) and the University of California. It is currently licenced to SteamTech, Inc., and Integrated Water Technologies, Inc. The technology is commercially available.

According to the researchers, advantages of HPO include the following:

- Significantly increases reaction rates and decreases remediation time.
- Increased mobilization of viscous contaminants.
- Avoids problems of mixing that are common in other in situ oxidation processes.
- Can be applied to large volumes.
- Efficiently treats contaminants at depths of over 100 ft.
- Is an economical alternative to excavation and pump-and-treat methods.

The primary limitation of HPO technology is the composition of the subsurface. HPO is most effective in sandy soils and does not work well in stratigraphies with interbedded clay layers, which impede steam flow.

Technology Cost
Hydrous pyrolysis/oxidation treatment is relatively simple and can be applied to large volumes of earth. This in situ process is capable of treating both soil and groundwater more quickly than pump-and-treat technologies. HPO has high capital costs but smaller long-term operating and

overall costs when compared to pump-and-treat technologies. In situ treatment can dramatically decrease the cost of cleanup by eliminating the need for surface treatment and reducing the costs of handling and disposal (D18431Q, p. 2; D20038U, p. 1; D175977, p. 13).

Remediation costs may vary from site to site based upon the type of contaminants, hydrogeology, contaminant concentrations, site conditions, the extent and depth of the contamination, and remediation goals. Large-scale cleanup using HPO could cost less than $20/yd^3 of soil treated in soils with a low clay content. Researchers state that the observed energy cost of heating soil to the boiling point by steam is approximately $1.50/yd^3 (D20038U, p. 1; D18431Q, p.2; D20109S, p. 1; D17601M, p. 2).

At the Visalia, California site, the total cost is expected to be approximately $20 million (D18785D, p. 39; D20039V, p. 2; D200986, p. 3; D19516Y, p. 19).

Information Sources

D175977, Davis, 1998

D17601M, U.S. DOE, undated web site

D18431Q, Science and Technology Review, 1998

D18785D, NATO, 1998

D19516Y, Industrial Wastewater, 1999

D20038U, vendor literature, undated

D20039V, vendor literature, undated

D200986, DOE, undated

D20109S, Subsurface Contaminants Focus Area, 1998

T0750

Stevens Institute of Technology

Trench Bio-Sparge

Abstract

The Trench Bio-Sparge (TBS) system is an in situ technology for the treatment of groundwater contaminated with organic compounds. The system employs diversion walls to direct the contaminant plume to a subsurface trench reactor, where treatment is achieved by physical and/or biological means. The technology has been field tested at the pilot scale but is not yet commercially available.

Sites with relatively homogeneous, shallow aquifers, bounded by an impervious stratum, contaminated with readily biodegradable compounds are the best candidates for TBS treatment.

Biodegradation and/or air sparging are implemented to reduce contaminant concentrations. Air sparging used in conjunction with diversion walls has the advantage of being able to treat large plumes that would typically require numerous sparging wells. The TBS reactor contains an attached growth zone, with subsurface packing material that provides a large surface area for microbial attachment, where optimal conditions for biodegradation are maintained.

The installation of a deep barrier over a large area may be cost prohibitive. Groundwater with a high velocity would require a larger reactor to achieve the necessary residence time which may also be cost prohibitive.

Technology Cost

Based on 1997 data, the estimated cost of a permeable reactive barrier (PRB) system ranged from approximately $405,000, corresponding to $1400 per 1000 gal of groundwater extracted to $585,000, corresponding to $225 per 1000 gal of groundwater extracted. The capital costs ranged from $373,000 to $500,000 and operation and maintenance (O&M) costs ranged from $32,000 to $85,000. Treatment wall costs included system construction, installation, monitoring, and analytical costs. Costs may vary due to differences in the subsurface matrix, thickness, and composition of wall. Data were provided by Geomatrix, the U.S. Navy, and the U.S. Coast Guard (D18882D, pp. 133, 145).

Information Source

D18882D, Federal Remediation Technologies Roundtable, 1998

T0751

eGeo Services, Inc.

PHOSter II

Abstract

PHOSter II™ is an in situ delivery system used to inject vapor-phase nutrients into groundwater and soil. The technology can be used to treat halogenated and nonhalogenated volatile organic compounds (VOCs); organic solvents; total petroleum hydrocarbons (TPH); benzene, toluene, ethylbenzene, and xylenes (BTEX); and methyl tertiary butyl ether (MTBE). Nutrients such as organic phosphorous are combined with a carrier gas and injected into the contaminated groundwater. The carrier gas creates a timed-release mechanism by slowing the dissolution of the nutrients in the water. Native microorganisms use these nutrients and air to degrade the contaminants.

The original technology, referred to as PHOSter™, was developed by scientists at the U.S. Department of Energy (DOE) Savannah River Technology Center in partnership with Oak Ridge National Laboratory and Ecova Corporation. The technology is currently marketed under the name PHOSter II. It is commercially available through Enviro-Logical Solutions, Inc., and eGeo Services, Inc. According to the vendor, the technology has been used in full-scale field applications in South Carolina, Florida, Georgia, Michigan, and Pennsylvania.

The vendor states that PHOSter II has the following advantages:

- Operates at low pressures and flow rates.
- Is a mobile treatment technology.
- Discharges negligible amounts of VOCs.
- Is efficient and cost effective.
- Treats sites with high concentrations of organic material.
- Can utilize existing wells.

The PHOSter II system is only applicable to contaminants that can be biologically degraded. In addition, it is only effective in settings where microbial activity is phosphorus limited. At sites with high contaminant concentrations, product recovery may be required during the initial treatment stage. Hydraulic conductivity and moisture content also determine the effectiveness of the PHOSter II technology.

Technology Cost

According to eGeo Services, Inc., the use of PHOSter II can reduce remediation costs because contaminants are treated in place and do not require secondary treatment (D21470A, p. 8). The vendor states that PHOSter II trailer units range in cost from $120,000 to $150,000. These units can simultaneously handle up to 12 injection points. PHOSter II skid units, which can only feed two points at one time, range from $60,000 to $80,000. Application costs are dependent on the vertical extent of the plume, site location, and site geography (personal communication: Gus Thompson, eGeo Services, Inc., 2001).

Information Source

D21470A, eGeo Services, Inc., undated

T0752

Stir-Melter, Inc.

Stir-Melter

Abstract
Stir-Melter, Inc., has developed the Stir-Melter™ vitrification system for the treatment of radioactive and hazardous wastes. The compact Stir-Melter system is a joule-heated melter that uses an impeller in the reactor to mix the wastes and create shearing forces within the glass. This aggressive mixing lowers the temperature required to achieve the glass waste form. Stir-Melter has operating units at Clemson University, the Department of Energy's (DOE's) Savannah River Site, and at Stir-Melter's Perrysburg, Ohio, plant. The technology is commercially available.

The vendor claims the following advantages using Stir-Melter:

- Increased capacity (up to eight times the capacity of similarly sized conventional melter systems)
- Decreased operating temperatures (30 to 100°C lower than conventional melter systems)
- Reduced energy costs
- Reduced size compared to other melter systems, due to improved melt kinetics obtained through the stirring action

Treatability studies will be required prior to treatment. Metal oxides have variable solubilities in glass. Systems are designed for an organic content under 20%. Materials for melter construction must be selected for their compatibility with the wastes to be treated. The mass and size of feed particles are limited by their impact on the impeller.

Technology Cost
In 1995, Stir-Melter, Inc., estimated that the price of treating wastes using Stir-Melter technology would range between $75 to $150 per ton. The factors cited by the vendor as having the greatest impact on processing costs were (in descending order): the amount of waste, site preparation requirements, the glass-making qualities of the waste stream, and waste handling/pretreatment requirements. Indirect costs associated with treatment may impact the cost estimate (D10322Q, p. 21).

According to the vendor, the cost of Sit-Melter systems are site-specific, depending on site requirements, desired treatment rates, and waste type. Treatability studies are used to determine system requirements (personal communication: Ken Kormanyos, Stir-Melter Project Manager, 1997).

Most of the cost data for vitrification technologies are estimates based on pilot-scale operations. Such data are suspect because they are based more on extrapolation than on experience. Such estimates are difficult to compare because the assumptions on which they are based may vary widely (D18248T, p. 55).

Many site-specific characteristics have an impact on vitrification technologies. One critical aspect of any thermal technology is the water content of the waste. Water dilutes feed material, requires energy to drive off, and physically limits the feed rate of waste. Feed preparation is another variable, which differs with the technology and with site-specific characteristics. Some technologies can accept complete barrels of waste at a time, while others require pretreatment and size reduction. Many estimates do not take into account site preparation and waste disposal costs. Only complete treatment life-cycle assessments can provide reliable comparison data, and such studies are, by definition, highly site- and waste-specific (D18248T, p. 55).

Information Sources

D10322Q, VISITT 4.0, 1995
D18248T, Sigmon and Skorska, 1998

T0753

Summit Research Corporation

Supercritical Water Oxidation

Abstract
Summit Research Corporation (SRCE) has developed plans for a bench-scale transpiring-wall supercritical water oxidation (SCWO) system to treat liquid organic wastes. As water is subjected to temperatures and pressures above its critical point (374.2°C, 22.1 MPa), it exhibits properties that differ from both liquid water and steam. At the critical point the liquid and vapor phases of water have the same density. When the critical point is exceeded, hydrogen bonding between water molecules is essentially stopped. Supercritical water sustains combustion and oxidation reactions because it mixes well with oxygen and with nonpolar organic compounds. Some organic compounds that are normally insoluble in liquid water become completely soluble (miscible in all proportions) in supercritical water. Some water-soluble inorganic compounds, such as salts, become insoluble in supercritical water.

The problems common to SCWO technologies have also been studied. These include reactor vessel corrosion, stress cracking, and salt plugging.

The transpiring-wall reactor has the potential to minimize many of the corrosion and deposition problems that have plagued previous SCWO studies. SRCE is developing a proprietary closed-cycle process that recirculates water for SCWO process at full system pressures. The design of the system was developed from previous work with gas turbine and rocket engines.

Technology Cost
Depending upon the plant capacity and the nature of the waste, the vendor claims that treatment cost ranges from \$0.10 to \$0.50/lb of waste (dry basis).

Information Source

Personal communication, Tomas McGuinness, Summit Research Corporation, December 12, 1997

T0754

SuperAll Products, Inc.

SuperAll #38

Abstract
SuperAll #38™ is a blend of ionic surfactants designed to break down hydrocarbon contaminants into microscopic particles. According to the vendor, it can be used for spill control,

bioremediation, and tank degassing and cleaning. When used for bioremediation, it increases the bioavailability of hydrocarbon contaminants, thereby increasing their rate of natural biodegradation. In this manner, SuperAll #38 may be used to benefit hydrocarbon landfarming operations and biopiles.

This product is currently in use and is commercially available from SuperAll Products, Inc., of Houston, Texas.

Technology Cost

SuperAll #38 costs about $14/gal and is available from distributors in the following quantities:

- 32-ounce spray bottle,
- 1/2 gal
- 1 gal
- 5 gal
- 55-gal drum
- 275-gal tote

Information Source

Personal communication, James Hack, 1997

T0755

Supercritical Carbon Dioxide Extraction — General

Abstract

Supercritical carbon dioxide extraction (SCDE) is an ex situ process currently being researched for the treatment of soil and debris contaminated with polychlorinated biphenyls (PCBs) and polycyclic aromatic compounds (PAHs) as well as for the removal of solvents from low-level solid mixed wastes and land disposal restricted (LDR) wastes.

The technology has been evaluated in laboratory- and bench-scale experiments and is not currently commercially available.

The process employs the supercritical fluid carbon dioxide as a solvent. When a compound (in this case carbon dioxide) is subjected to temperatures and pressures above its critical point (31°C, 7.4 MPa, respectively), it exhibits properties that differ from both the liquid and vapor phases. Polar bonding between molecules essentially stops. Some organic compounds that are normally insoluble become completely soluble (miscible in all proportions) in supercritical fluids. Supercritical carbon dioxide sustains combustion and oxidation reactions because it mixes well with oxygen and with nonpolar organic compounds.

SCDE offers several advantages over conventional solvent extraction technologies:

- Minimization of organic liquid waste generation.
- Allows for rapid extraction of toxics and relatively easy solute concentration and recovery.
- Cheaper than competing technologies.
- Low surface tension of supercritical fluids enables penetration into microporous soil matrices.
- More acceptable to the public than incineration or in situ vitrification.
- Supercritical fluid possesses low viscosity and high diffusivity and its solvent power is easily "tunable."

Elevated water content can have a negative impact on SCDE performance. Research also indicates that process performance is affected by soil type (possibly due to differences in the

soil's organic content). Motor oils and machine coolants containing paraffin and long-chain polymers tend to be difficult to extract by SCDE. Two or more vessel volume exchanges are required to extract these types of compounds. Some SCDE technologies remove all organics from the soil, not just targeted contaminants. The treated soil may be unsuitable for reuse since it is now inert.

Technology Cost

The following cost estimate was prepared for the SCDE technology currently being researched at Syracuse University (T0762). In 1995, Tavlarides et al. estimated that the costs of the supercritical fluid extraction (SFE) of soils contaminated with PCBs would range from \$220 to \$270/m^3 of soil treated. This price estimate was based on a scale-up of the results of laboratory-scale treatability studies. The researcher stated that this estimate compared favorably to other competing treatment technologies (D14667S, pp. 4–5).

It is assumed that a full-scale SFE facility could treat 12,000 m^3 of soil and sediments per year, or 24,000 m^3 of sand per year (personal communication, Lawrence Tavlarides, Syracuse University, January 1997).

According to the principal investigator, the cost of material handling is the single most important factor in SFE economics. Soil-handling costs were estimated at \$109 per cubic meter of soil, almost one-half of the total treatment costs (personal communication, Lawrence Tavlarides, Syracuse University, January 1997).

Information Source

D14667S, Tavlarides et al., 1995

T0756

Supercritical Water Oxidation — General

Abstract

As water is subjected to temperatures and pressures above its critical point (374.2°C, 22.1 MPa), it exhibits properties that differ from both liquid water and steam. At the critical point the liquid and vapor phases of water have the same density. When the critical point is exceeded, hydrogen bonding between water molecules is essentially stopped. Supercritical water sustains combustion and oxidation reactions because it mixes well with oxygen and with nonpolar organic compounds. Some organic compounds that are normally insoluble in liquid water become completely soluble (miscible in all proportions) in supercritical water. Some water-soluble inorganic compounds, such as salts, become insoluble in supercritical water.

The unique properties of supercritical water, when combined with an oxidant such as air, oxygen, or peroxide, create an excellent reaction medium. The process, called supercritical water oxidation (SCWO), has been proven to be capable of destroying organic contaminants as well as some inorganic substances. SCWO is also known as hydrothermal oxidation (HTO).

Researchers list the following advantages of SCWO technology:

- SCWO promises rapid, efficient oxidation of organic materials in aqueous media without generation of products of incomplete combustion (PICs), particulate material, or oxides of nitrogen and sulfur.
- SCWO may provide an efficient means of separating dissolved heavy metals from dilute aqueous solutions.
- SCWO may offer operation as a totally enclosed facility with no uncontrolled releases to the environment.

Researchers list the following limitations of SCWO:

- Processing wastes containing chlorine, sulfur, or phosphorus generates acids that must be neutralized in the reactor to prevent corrosion.
- Neutralizing acids created during processing can cause the formation of salts that can plug reactor components.
- Systems are generally limited to treating waste stream solutions and slurries containing 2 to 25% organics with a maximum particulate size of 100 μm.

Technology Cost

In 1990, Thomason estimated the cost of operating a SCWO facility based on results of MODAR pilot-scale studies and plans for a commercial facility. The primary factors influencing costs of a SCWO unit were the treatment capacity of the facility and the organics concentration of the feed material (D11985R, p. 41). MODAR technology was recently acquired by General Atomics.

Based on information from the Eco Waste commercial pilot facility in 1995, costs for a full-scale SCWO unit were estimated to be 10 to 20 cents per gallon of waste treated (D11868N, p. 3). Detailed cost estimates are provided for the Eco Waste system (T0877), the Foster Wheeler system (T0314), and the General Atomics system (T0329).

In 1996, a cost estimate was prepared for the U.S. Department of Energy (DOE) for constructing supercritical gravity pressure vessel (SGPV) systems to treat low-level mixed waste (mixed wastes are materials that contain both hazardous and radioactive components). This analysis estimated costs of SGPV systems capable of processing waste at rates of 240, 400, 480, and 600 gal/min (gpm). For this analysis, it was assumed that the gravity vessel would be composed of a titanium with a 1% rubidium alloy content, grade 8 or 18. The cost per pound of the reactor material was estimated to be $21.50/lb (D17156M, pp. 14–17). Additional information cost information is available for the GeneSyst System (T0332).

Information Sources

D11985R, Thomason et al., 1990

D11868N, Stadig, 1995

D17156M, Rappe, 1997

T0757

Surbec-ART Environmental, L.L.C

Soil Washing

Abstract

The Surbec-ART Environmental, L.L.C. (Surbec), soil washing technology is a process based on mining and mineral processing principles that incorporates physical and chemical separation techniques (D12463A, p. 3). The technology separates and treats oversized fractions and sand fractions so that they can be placed back on the site as clean backfill. Contaminants are concentrated in the fines, and this fraction can be managed separately for further treatment or disposal.

The Surbec soil washing technology is commercially available. It has been used in The Netherlands for more than 10 years and has treated over 600,000 tons of contaminated soil.

According to the vendor, the soil washing system has several advantages:

- Focuses treatment on the contaminated fraction of soil.
- Minimizes the volume of contaminated material.
- Treats a wide variety of contamination.

In general, several factors limit the applicability and the effectiveness of most soil washing technologies:

- Fine soil particles (e.g., silt, clays) may require the addition of a polymer to remove the washing fluid.
- Complex waste mixtures (e.g., metals with organics) make formulating washing fluid difficult.
- High humic content in soil may require pretreatment.
- Aqueous waste streams require treatment.

Technology Cost

In general, the estimated cost for the Surbec-ART Environmental, L.L.C., soil washing technology ranges between $136 and $226 per ton. Table 1, adapted from data provided by the vendor, shows a breakdown of costs and the factors that influence costs (D12463A, p. 16).

The cost of the soil washing technology is affected by soil characteristics such as the moisture content, the clay content or particle size distribution, the soil pH, the total organic carbon content, and the cation exchange capacity. According to the vendor, the technology is most cost effective when used to treat more than 20,000 tons of contaminated soil that contain less than 30% clay or silt. The system throughput and washing/flushing solvent components/additives also affect the overall costs (D12463A, pp. 35, 37; D21365A, p. 3; D21906H, p. 1).

The total cost of cleanup at the King of Prussia Technical Corporation Superfund site in Camden County, New Jersey, was $7,700,000, including off-site disposal cost for the sludge cake. Approximately 19,200 tons of contaminated soil and sludge was treated. The contaminants of primary concern were chromium, copper, and nickel (D12463A, p. 28).

At the Field Brook site near Ashtabula, Ohio, the total cost of the pilot-scale testing and demonstration was $638,670. Most of the cost was attributed to the procurement of capital equipment, plant operations, and laboratory analysis. Equipment was leased or acquired from other Department of Energy (DOE) sites in order to reduce costs. The full-scale remediation

TABLE 1 Full-Scale Cost Estimating for Surbec Environmental, L.L.C., Soil Washing Technology

Mass of soil to be treated (tons)	5,000	20,000	100,000
Plant throughput capacity (tons/hr)	15	25	25
Treatment duration (weeks)	12	28	70
Total project duration (weeks)	16	36	78
	Costs in Dollars		
Preparation activities	241,000	664,000	2,120,000
Soil washing activities	448,000	1,988,000	9,940,000
Product (i.e., cleaned soil) management activities	49,000	196,000	980,000
Residual management activities	238,000	952,000	4,760,000
10% fines	476,000	1,904,000	9,520,000
20% fines	714,000	2,856,000	14,280,000
30% fines			
Closure activities	132,500	360,000	1,200,000
Total project cost ($/ton)^2	158	149	136
10% fines	192	183	170
20% fines	226	217	204
30% fines			

Source: Adapted from D12463A.

of this site is expected to cost between \$328 and \$460/m^3 of soil treated. This would result in an approximate savings of \$25,000,000 over the excavation–packaging–landfilling treatment option (D193684, pp. 6, 7; D19849G, p. 6).

According to the vendor, a pilot-scale soil washing system was used in Duphar, The Netherlands, to treat 50 tons of soil contaminated with lindane. The vendor states that the unit cost of the demonstration was \$50 per ton (D21365A, p. 9).

Information Sources

D12463A, Alternative Remedial Technologies, Inc. (ART), undated

D193684, Mann, 1999

D19849G, Kulpa, et al., undated

D21365A, U.S. EPA Reachit, undated

D21906H, Interstate Technology and Regulatory Cooperation Work Group, 1998

T0758

Surface Remediation Specialists

Centrifugal Shot Blast

Abstract

Surface Remediation Specialists (formerly Concrete Cleaning, Inc.) has developed a centrifugal shot blast technology that uses hardened steel shot to remove radioactive coatings from concrete. The shot is propelled at a high rate of speed and impacts the concrete surface, abrading the contaminated surface. The steel shot is recovered and reused until the pulverized shot is too small to use. The generated debris is recovered using an attached vacuum and dust collection system.

The technology is commercially available. Surface Remediation Specialists provides equipment and staff to perform decontamination tasks.

According to researchers, the centrifugal shot blast technology offers the following advantages:

- Generates less waste material requiring disposal than baseline technologies (i.e., scabbling).
- Wastes collected during removal process, no separate containment required.
- Can be used to remove only surface coatings, leaving a smooth processed surface.
- More economical that baseline technology for processing areas greater than 1900 ft^2.

The surface must be dry to prevent the removed substrate from clogging the hoses and screens within the unit. Noise levels encountered during the use of the systems can reach 97 dB, requiring hearing protection. Problems were encountered with the design of the dust collection system during a technology demonstration for the U.S. Department of Energy (DOE).

Technology Cost

During a DOE evaluation of centrifugal shot blast technology in 1998, the vendor supplied a cost estimate for treating 5000 and 40,000 ft^2 of contaminated material. Cost estimates ranged from \$5 to \$14/ft^2, depending on total area treated and type of removal (removal of coatings versus removal of coatings and concrete) (D189097, p. 16). Details of this estimate are given in Table 1.

As part of the evaluation, a cost estimate of the centrifugal shot blast technology was prepared based on the demonstrated decontamination of 800 ft^2 of concrete. The vendor provided personnel and equipment for which timed and measured activities were recorded to determine achievable production rates. These data included activity duration, work crew composition,

TABLE 1 Vendor-Supplied Cost Estimate of Centrifugal Shot Blasting Technology

Type of Removal	Total Cost ($)	Cost per Square Foot ($)
5000 ft^2, removal of coating only	35,000	7
5000 ft^2, removal of coating and $\frac{1}{4}$-inch concrete	70,000	14
40,000 ft^2, removal of coating only	200,000	5
40,000 ft^2, removal of coating and $\frac{1}{4}$-inch concrete	480,000	12

Source: Adapted from D189097.

equipment used to perform the activity, supplies used, and training courses required and attended (D189097, p. 13). A summary of cost variable conditions is provided in Table 2.

The total cost for decontamination of 800 ft^2 of concrete using centrifugal shot blast technology was approximately $22,500. The estimated cost for the accepted baseline technology (mechanical scabbling) was 75% less than the centrifugal shot blast method. However, researchers state that this price discrepancy is caused by extremely limited scope of the demonstration. Most of the difference in cost was due to higher labor and transport costs, which could not be fully offset in a small demonstration. Also, since the shot blasting method generates less primary waste, disposal costs for larger treatment areas would be significantly less than for sites treated using the baseline technology (D189097, pp. 15–16).

Some costs are omitted from this analysis to facilitate site-specific use in site comparison. The laboratory indirect expense rates for common support and materials were omitted, as were engineering, quality assurance, administrative costs, and taxes on services and materials (D189097, p. 13).

Researchers estimate that the cost for centrifugal shot blasting would be approximately equal to that of mechanical scabbling for treating an area of 1900 ft^2 and would be cheaper than the baseline technology for treating larger areas (D189097, p. 16).

Information Source

D189097, U.S. DOE, 1998

T0759

Surfactants — General

Abstract

Commercially available surfactants are compounds used to enhance the remediation or recovery of toxic or hazardous hydrophobic organic compounds (HOCs) in soil or groundwater. Surfactants are surface-active compounds that can increase the mobility and solubility of contaminants. This surface activity is a result of surfactant structure: Each molecule is composed of a hydrophobic (“water-fearing”), nonpolar portion and a hydrophilic (“water-liking”), polar portion. Surfactants concentrate at interfacial regions such as air–water or oil–water junctures and are classified according to the nature of the polar portion, which is nonionic (neutral), anionic (negatively charged), or cationic (positively charged).

The application of surfactants can enhance remediation or recovery of contaminants by increasing their mobility and solubility. Surfactants can thus be used to enhance ex situ soil washing, in situsoil flushing, non-aqueous-phase liquid (NAPL) pump-and-treat applications, and in situbiodegradation. Cationic surfactants have been shown to improve the capacity of soil

TABLE 2 Centrifugal Shot Blasting Versus Baseline Mechanical Scabbling—Summary of Cost-Variable Conditions

Cost Variable	Centrifugal Shot Blasting	Mechanical Scabbling
	Scope of Work	
Quantity and type of material	800 ft^2 of concrete with multiple paint layers	800 ft^2 of concrete with multiple paint layers
Location	Service floor of CP-5 research reactor (performance observed)	Service floor of CP-5 research reactor (estimated, not observed)
Nature of work	Reduce radiological levels on the floor via paint removal only	Reduce radiological levels on the floor via $\frac{1}{4}$-inch paint and concrete removal
	Work Environment	
Worker protection	Personal protective equipment (PPE) and respirators	PPE and respirators, construction of temporary containment tent
Level of contamination	Low-activity, fixed contamination	Concrete chips and airborne dust created by equipment
	Work Performance	
Demonstration activities	Testing in open area with some vertical edges, 13-inch cutting width, self-propelled unit	Based on unconfined area, crew of three, one operator and two to support personnel, 11-inch floor unit
Production rates	One unit at 310 ft^2/hr (observed)	one unit at 200 ft^2/hour (based on experience)
Equipment and crew	One unit provided by vendor with modifications; a two-person crew (one operator, one stand-by); one health physics technician supporting activities	One unit; two decontamination technicians; one health physics technician supporting activities
Primary waste	2.5-ft^3 mix of paint and concrete powder	24.0 ft^3 of paint and concrete rubble (based on historical experience)
Secondary waste and consumables	filter hose, process filters, PPE, cleaning brushes, plastic matting for shot collector, 100 lb of shot	Worn scabbling bits, swipes, PPE, and the dismantled contamination tent
Work process steps	Blast the surface with one machine and collect debris and spent shot in the connected dust collector system	Scabble the surface, leaving debris and airborne contaminants; debris collected and disposed manually
End condition	Paint coating removed, leaving a smooth, bare concrete surface	$\frac{1}{4}$-inch mix of paint and concrete removed, leaving rough, bare concrete surface

Source: Adapted from D189097.

to sorb HOCs such as polyaromatic hydrocarbons (PAHs), making cationic surfactants potentially useful as an in situbarrier technology.

Biosurfactants are naturally occurring surfactants synthesized by certain strains of bacteria, yeasts, and fungi. See Biosurfactants—General (T0119) in the RIMS library/database for more information on this type of surfactant.

Temperature sensitivities can be a limiting factor when using surfactants in groundwater systems. Low temperatures can cause the surfactant concentration to drop below the cation exchange capacity (CMC), rendering the surfactant useless. This effect can be abated with surfactant engineering or by using a co-surfactant.

The mobilization of NAPL, particularly dense DNAPL, in response to surfactant flooding can be used to enhance remediation based on pump-and-treat extraction techniques because it increases the soluble contaminant levels.

Technology Cost

The cost of implementing an in situ surfactant flood will vary significantly from site to site. Because costs of full-scale implementation do not exist, currently available cost estimates are based on hypothetical examples and extrapolation from field pilot tests. For typical waste sites having contamination limited to the upper 15 m (49 ft) below ground surface, estimated costs range from \$1.4 million per hectare to \$18 million per hectare, or approximately \$90 to \$990/m^3 (\$65 to \$750/yd^3) of treated contaminated soil (D16070D, p. ES-4).

TABLE 1 Estimated Costs for Remediating a $\frac{1}{2}$-Acre Site Contaminated with PCE[a] Using Surfactant Solubilization[b]

	Initial Capital Costs (\$ × 1000)	Annual Operating Costs (\$ × 1000)	Present Worth Costs[c] (\$ × 1000)
Injection and recovery wells[d]	72	—	72
Air stripping/scrubbing	258	—	258
Additional plant equipment[e]	335	—	335
Sheet piling[f]	590	—	590
Surfactant to fill aquifer[g]	1054	—	1054
Chemicals[h]	—	57	224
Electricity	—	23	90
Fuel	—	13	51
Labor	—	80	313
Plant maintenance	—	33	130
Well maintenance	—	27	106
Surfactant lost to biodegradation	—	51	200
Total	—	—	3423

[a] PCE, tetrachloroethylene.
[b] The groundwater aquifer is assumed to be contaminated with 5% PCE (calculated as the volume of PCE per volume of aquifer contaminated).
[c] Present worth costs are calculated using a 12% interest rate and 3% inflation over a 5-year remediation, which results in a present worth discounted rate of 8.737%.
[d] Based on 45 wells drilled to a depth of 40 ft at a cost of \$40/ft.
[e] Includes a catalytic incinerator to remove PCE from the airstream, plant instrumentation, and a contingency for other necessary equipment.
[f] Costs for sheet piling are based on \$25/ft^2.
[g] Includes surfactant lost to bioremediation.
[h] Includes costs for sodium hydroxide and a catalyst.

In 1991 the cost of soil flushing with recovery and recycling of surfactant was estimated to be less than $200/yd^3 (D16071E, p. 967).

Information Sources

D16070D, Westinghouse Savannah River Company, January 1997

D16071E, Clarke et al., November 1994

T0760

Surtek, Inc.

Surfactant Remediation

Abstract

Surtek, Inc.'s, surfactant remediation, also known as in situ soil washing, is a technology that uses surfactants, alkalis, and polymers to increase the recovery of non-aqueous-phase liquids (NAPLs) from soil and groundwater. This in situ flushing technology is designed to improve the effectiveness of pump-and-treat systems. The technology has been demonstrated in the field and is commercially available through Surtek.

The surfactants used with the Surtek technology can increase contaminant mobility in two ways. First, they can increase the solubility of the contaminant in water. This process accelerates the removal of sorbed contaminants by increasing their concentration in solution. Second, surfactants can reduce interfacial tension of the NAPLs, which results in direct mobilization. Direct mobilization may allow contaminants to be extracted more efficiently.

Alkali compounds are used in the Surtek process to reduce the interfacial tension between the oil phase and the aqueous phase. In addition, an alkaline agent neutralizes rock and clay surfaces and reduces the amount of exchangeable calcium and magnesium ions from the soil surface. Both of these functions reduce surfactant and polymer adsorption into the soil matrix.

Polymers increase the viscosity of the soil washing fluids. Increased viscosity provides mobility control, which reduces the fingering of the displacing fluid past the displaced fluid. It also helps ensure that the contaminated area is efficiently contacted by the soil washing solution.

Surtek's surfactant remediation is limited by the same factors that affect any pump-and-treat technology. Performance may be reduced in areas with low hydraulic conductivity or high soil heterogeneity. Incorrect formulation and application of the Surtek method can also make NAPLs more mobile, thereby increasing their potential to migrate to previously uncontaminated areas. In addition, no complete process for the treatment of fluid extracted by the process has been identified.

Technology Cost

According to the vendor, typical subsurface contaminant recovery applications cost about $75 to $150/yd^3. In contrast, costs for removal and incineration can range from $200 to $300/yd^3 (D14453G, p. 5).

The cost of a pilot-scale demonstration of Surtek's surfactant remediation at a site in Laramie, Wyoming, was estimated to be $2,500,000, or $100/yd^3. A full-scale application at this site was estimated to cost approximately $570,000 per acre (for 100 acres treated). Costs for this technology are highly variable and depend upon site-specific characteristics such as amount, type, and depth of contamination (personal communication, Tom Sale, CH2M Hill, 1997).

TABLE 1 Costs of Using Surtek ASP Process for Oil Recovery

	Sandstone Field 1	Sandstone Field 2	Sandstone Field 3	Sandstone Field 4
Alkali injected	0.8% (by weight)	1.25% (by weight)	1.25% (by weight)	1.0% (by weight)
Surfactant injected	0.1% (by weight)	0.1% (by weight)	0.3% (by weight)	0
Polymer injected	1050 mg/liter	1425 mg/liter	1200 mg/liter	800 mg/liter
Total chemical cost	$375,000	$2,518,000	$1,009,000	$1,585,000
Incremental ASP oil recovered (barrels)	275,000	1,143,000	270,000	2,010,000
Chemical cost per barrel of incremental ASP oil recovered	$1.46	$2.20	$3.74	$0.79

Source: Adapted from D22984Z.

Surtek also has extensive experience using surfactants to recover oil. Table 1 lists the chemical costs involved in using Surtek's alkaline–surfactant–polymer (ASP) process for oil recovery.

Information Sources

D14453G, Surtek, Inc., undated

D22984Z, Surtek, Inc., undated

T0761

Sybron Chemicals, Inc.

ABR (Augmented Bioreclamation) Microbial Blends

Abstract

Sybron Chemical, Inc., produces microbial cultures that can be used for bioaugmentation of soils or groundwater contaminated with organics such as hydrocarbons, gasoline, and diesel. The microbial blends are proprietary and commercially available and have been used in multiple full-scale applications.

The microbial cultures can be applied in a number of remedial techniques, including landfarming, vacuum heap, recirculating leachbeds, or bioreactors. The cultures are distinct in regard to target contaminants the different blends treat. All require proper conditions (pH, temperature, nutrients, aeration, and moisture) to function efficiently in biodegrading the target compounds. Sybron also offers a proprietary nutrient source, BioBlend, that can be used with its microbes.

Technology Cost

A site in northern New Jersey was to be remediated by Sybron using the ABR® Hydrocarbon blend in 1995/1996. This application was an in situ soil remediation described in Case Study 1 (see D14650J, p. 21). The projected cost for the soil clean-up was approximately $11 per ton or $14.50/yd^3 for the 35-acre treatment area.

Information Source

D14650J, vendor literature

T0762

Syracuse University

Supercritical Fluid Extraction

Abstract

Syracuse University is investigating possible applications of supercritical fluid extraction (SFE) to the treatment of soils and sediments contaminated with polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). At the critical point, liquid and vapor phases have the same density. When a compound (in this case carbon dioxide) is subjected to temperatures and pressures above its critical point, it exhibits properties that differ from both the liquid and vapor phases. Supercritical fluids sustain combustion and oxidation reactions because they mix well with oxygen and with nonpolar organic compounds. Some organic compounds that are normally insoluble become completely soluble (miscible in all proportions) in supercritical fluids. The Syracuse program has used laboratory-scale studies for proof-of-concept testing and has developed a bench-scale system (1-kg capacity) to evaluate the technology on soil samples. The technology is not currently commercially available.

Syracuse claims the following advantages of SFE:

- Cheaper than competing technologies.
- Low surface tension of supercritical fluids enable penetration into microporous soil matrices.
- More acceptable to the public than incineration or in situ vitrification.
- The supercritical fluid possesses low viscosity and high diffusivity, and its solvent power is easily "tunable."

Moisture content of the soil has an effect on initial extraction rates of PCBs, although the final extraction efficiency is not affected. The technology removes all organics from the soil, not just targeted contaminants. The treated soil may be unsuitable for reuse since it is now inert.

Technology Cost

In 1995, Tavlarides et al. estimated the cost estimate for SFE of soils contaminated with PCBs would range from \$220 to \$270/m^3 of soil treated. This price estimate was based on a scale-up of the results of laboratory-scale treatability studies. The researcher stated that this estimate compared favorably to other competing treatment technologies (D14667S, pp. 4–5).

It is assumed that a full-scale SFE facility could treat 12,000 m^3 of soil and sediments per year, or 24,000 m^3 of sand per year (personal Communication, Lawrence Tavlarides, Syracuse University, January 1997).

According to the principal investigator, the cost of material handling is the single most important factor in SFE economics. Soil handling costs were estimated at \$109/m^3 of soil, almost one-half of the total treatment costs (personal communication, Lawrence Tavlarides, Syracuse University, January 1997).

Information Source

D14667S, Tavlarides et al., 1995

T0763

Tallon, Inc.

Vitrokele

Abstract

The Tallon Vitrokele™ technology combines soil washing and metals extraction processes to treat soil contaminated with heavy metals and organics. The continuous process integrates three key stages: pretreatment/physical recovery, organic extraction/recovery, and metal extraction/recovery. The pretreatment/physical recovery phase involves magnetic, gravity, and screening processes. The organic extraction/recovery phase uses chemical extraction and physical recovery. The final phase, metal extraction/recovery, uses chemical extraction and recovery with patented Vitrokele chelating adsorbents.

Research and development of this technology began in 1989. According to the vendor, the Vitrokele technology is patented in the United States. The technology has been used in a full-scale remediation at the Longue Pointe site in Montreal, Canada. The vendor states that pilot studies are underway at a number of sites in the United States, Europe, and Australia.

According to the vendor, the technology has several advantages:

- Offers compact treatment systems.
- Has moderate reagent costs.
- Treats fine soils and sands.
- Produces medium-grade metal concentrates for disposal.

Contaminants treated by this technology are recovered for recycling, destruction, or treatment, which must be conducted with separate technologies.

Technology Cost

According to the vendor, average operating costs range from approximately $100 to $150 per dry ton (D17631S).

Information Source

D17631S, Environmental Engineering World, 1996

T0764

Tarmac Environmental Company, Inc.

Thermal Desorption

Abstract

The Tarmac technology is an ex situ low-temperature thermal desorption process. This technology includes a natural gas-fired rotary drier, a modified thermal oxidizer, and a baghouse to control air emissions. Tarmac's thermal desorption technology has been used to remediate soils contaminated with gasoline, diesel, marine bunker fuels, benzene, toluene, ethylbenzene, and xylene (BTEX), polynuclear aromatic hydrocarbons (PAH), and other volatile organic compounds (VOCs). This technology can be used in a stationary or portable unit.

According to the vendor, the technology has the following advantages:

- Removal and destruction of the petroleum contamination eliminate future liability and potential environmental problems.
- It provides a reliable and cost-effective option to landfill disposal.
- It allows the reuse of treated soils in a variety of ways, including backfill at the site of origin, reclaiming aggregate or coal pits, general clean fill, crushed aggregate sales, asphalt mix sales, concrete mix sales, and cover for sanitary landfills.

Contaminated soil is excavated and stockpiled prior to treatment. Because the composition of the stockpiled soil is not monitored continuously, process control problems can occur if moisture and hydrocarbon contents vary over extreme ranges. Clay soils, to which hydrocarbons tend to be more tightly adsorbed, are typically more difficult to treat than sandy soils.

This technology is currently commercially available.

Technology Cost

The estimated price for this technology is $20 to $100 per ton. This estimate may not include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals.

Factors that have a significant effect on unit price include the following:

- Quantity of waste
- Initial contaminant concentration
- Target contaminant concentration
- Moisture content of soil
- Characteristics of soil
- Utility/fuel rates
- Characteristics of residual waste
- Waste handling/preprocessing
- Site preparation
- Amount of debris with waste (D10180U, p. 10)

Information Source

D10180U, VISITT Version 4.0

T0765

Technology Scientific, Ltd. (TSL)

Flow Consecutor Technology

Abstract

Technology Scientific, Ltd. (TSL), asserts that it has developed an innovative technology called the flow consecutor (FC) technology. The technology uses an intensively acting tubular agitator known as the FC to replace traditional agitators generally used in processing multi-phase mixtures. Currently (December 9, 1996), the FC technology is proprietary and unpublished.

The technology does not treat wastes but is used as a mixing apparatus in conjunction with other treatment technologies such as flotation (used to separate coal agglomerates), traditional screening, and sedimentation (both used to separate solids).

According to the developer, the FC agitator has the following advantages over traditional agitators:

- Lower energy consumption
- Smaller space requirements
- Increased reliability due to lack of moving parts
- Increased effectiveness produced by optimization of component processes
- Environmental friendliness resulting from an enclosed piping system

All information was supplied by the vendor and has not been independently verified.

Technology Cost
No available information.

T0766

Technology Visions Group, Inc. (formerly Orbit Technologies, Inc.)

Polymer Encapsulation Technology

Abstract
Polymer encapsulation technology (PET) was designed to stabilize radioactive materials and wastes. Polymer encapsulation uses nonvolatile polymers with excellent heat resistance, low water solubility, chemical stability, and excellent radiation resistance. Once materials have been mixed with the encapsulant, the mixture expands and hardens. This process prevents radioactivity from escaping and confines radioactive particles to the polymer structure.

There is a patent pending for PET, but the technology has not yet been applied as a full-scale system. The vendor is also marketing this technology in Korea, Japan, Taiwan, and China.

Technology advantages include:

- PET is ideally suited for the treatment of granular materials.
- The process uses off-the-shelf components, which simplifies treatability testing and eases concern of technology reliability.
- The technology is a low-cost process that uses no large equipment.
- Cure time of the material can be controlled by varying the amount of catalyst.

Technology limitations include:

- Technology is limited to stabilization of nonaqueous solid materials.
- Long-term durability of the PET waste form is not known.
- Wastes with high concentrations ($>$ 500 ppm) of easily leached contaminants may not be sufficiently immobilized by PET processing.

Technology Cost
In 1999, the U.S. Department of Energy (DOE) prepared a cost estimate for PET treatment of salt wastes containing heavy metals and organics. The estimate compared PET treatment with the current baseline (cement encapsulation). It is assumed that waste loading for the cement system would be 10%, while the PET system would allow for a 30% waste loading. An analysis of operations and maintenance for the PET system was not performed. It was assumed that the basic mixing apparatus and extruder could be purchased off the shelf and that facility requirements would be similar for the two options (D20937K, p. 12).

Final disposal costs were estimated to be \$500/ft^3 of waste based on data from a commercial mixed waste disposal facility. From previous studies, it was assumed that each cubic foot of salt would require 71.7 lb of polysiloxane. For cement-based disposal, each cubic foot of waste requires 10 ft^3 of cement (D20937K, p. 12).

Based on the above estimate, mixing and disposal costs for PET were $\$1904/ft^3$, while those for the concrete system were placed at $\$5000/ft^3$. The estimated savings factor of using the PET system was 2.6. It was estimated that a facility processing approximately one 55-gal barrel of waste per day would cost between \$60,000 and \$1,000,000, and the cost of permitting the facility was placed at \$200,000. This compares favorably with a comparable high-temperature vitrification system. Development, design, installation, and capital costs were placed at \$10,000,000 or more (D20937K, p. 12).

According to the vendor, PET is over 50% more cost effective than alternative treatment and storage technologies for low-level calcine waste (D20637B, p. 4).

Information Sources

D20637B, Orbit Technologies, 2000
D20937K, U.S. DOE, 1999

T0767

TechTran Environmental, Inc.

RHM-1000 Process

Abstract

The RHM-1000 process is an ex situ technology for the treatment of media contaminated with radionuclides and heavy metals. RHM-1000 is a proprietary fine powder designed to facilitate chemical binding and physical separation. According to the developer, this technology can absorb, adsorb, and chemisorb most radionuclides and heavy metals in water, sludges, or soils (preprocessed into slurry), resulting in coagulating, flocculating, and precipitating reactions. This company no longer performs remediation, and the technology is not commercially available.

According to the vendor, the technology can be used to (1) remediate water and sludges contaminated with radionuclides and heavy metals, (2) restore groundwater from mining operations, (3) treat naturally occurring radioactive materials (NORMs) in water or scale from petroleum operations, and (4) remediate man-made radionuclides stored in tanks, pits, barrels, or other containers.

Technology Cost

In 1992 the vendor claimed that high-volume treatment, solids removal, and continuous chemical monitoring can be incorporated into a turnkey on-site remediation process with total costs as low as \$1.00/1000 gal of waste treated (D16027A, p. 800).

Information Source

D16027A, Daniels and Lolcama, 1992

T0768

Tekno Associates

Biolift

Abstract

The Biolift™ slurry bioreactor is an ex situ technology for the bioremediation of soil or sludges contaminated with organic hazardous wastes. Slurry-phase bioremediation, while more costly than other methods of bioremediation, requires less area and generally less time than other biological processes such as soil heaping or composting. Slurry-phase bioremediation is regarded as being very good for the treatment of soils containing high concentrations of very oily or tarlike compounds.

The Biolift reactor has been used to treat soils contaminated with benzene, toluene, ethylbenzene, and xylene (BTEX), total petroleum hydrocarbons (TPHs), and polynuclear aromatic hydrocarbons (PAHs). The process uses microorganisms to oxidize organic compounds, yielding innocuous by-products.

Technology Cost

Compared to other forms of bioremediation, slurry-phase reactors such as Biolift typically cost more than other forms of bioremediation (see Table 1). However, slurry-phase treatment typically requires less space and time than alternative bioremediation methods (D12501Z, p. 63).

Typically about 50% of the total cost in the field-scale remediation of sludge or soil is labor. To reduce labor costs, the size of the reactor and the process should be appropriately designed so the least amount of time is spent on-site. For sites where treatment is expected to be completed in less than 1 year, portable reactors should be considered to avoid the cost of erecting large-scale, permanently sited equipment (D10061O, pp. 17–18).

According to the vendor, economic analysis indicates that the combined capital and operating costs for the Biolift reactor may range from \$120 to \$250/yd^3 of contaminated soil or sludge. These costs do not reflect ancillary costs such as excavation, prescreening, or dewatering. The vendor further states that costs are greatly influenced by the size of the project, the cleanup schedule, and the available biodegradation kinetics (personal communication, Gunter Brox, Tekno Associates, October 1996).

Estimated costs associated with various stages of slurry-phase reactor systems are summarized in Table 2. The table compares the cost of two sizes of Biolift reactors used to treat 20,000 yd^3 (15,300 m^3) of contaminated soil in 1993. The following is an explanation of some of the costs:

- The permitting and regulatory costs given assume that the treatment is part of a Resource Conservation and Recovery Act (RCRA) remedial action and that the effluent is discharged to a publicly owned treatment works (POTW).
- Labor and utility costs are greater for the smaller reactor because it would take approximately 12.3 years to complete treatment compared to 3 years with the larger reactor.
- Supply and consumable costs include lime (to maintain pH) and nutrients.
- Effluent disposal costs assume that water will be discharged to a POTW and soil will be backfilled and compacted back to the site (D10061O, pp. 19–20).

The costs given are dependent on site and contaminant characteristics and may vary by +50% to −30%.

TABLE 1 Cost Comparison of Biological Treatment Methods

	Typical Cost (\$)	
Method	yd^{-3}	m^{-3}
Solid phase	50–80	65–104
Composting	100	130
Slurry phase	100–150	130–196

Source: From D12501Z, pp. 73–74.

TABLE 2 Estimated Costs Associated with Two Sizes of Slurry-Phase Reactor Systems For Treatment of 20,000 yd^3 (15,300 m^3) of Contaminated Soil in 1993

	Cost ($)[a]	
Cost Category	275-m^3 Reactor	1125-m^3 Reactor
Site preparation		
Excavation	80,000	80,000
Decontamination facilities	8,500	8,500
Utility connections	35,000	35,000
Emergency and safety equipment	12,000	12,000
Permitting and regulatory	15,000	15,000
Capital equipment		
Mill	65,000	65,000
Screen	20,000	20,000
Reactor and mechanism	125,000	256,000
Engineering	41,500	41,500
System design	23,000	23,000
System construction	120,000	241,000
Startup and fixed		
H & S monitoring	2,000	2,000
Establish operating procedures	9,000	9,000
Equipment mobilization	7,500	7,500
Scale-up optimization	50,000	50,000
Other		
Labor	3,750,000	1,290,000
Supply and consumable	27,000	15,000
Utility	110,000	43,000
Effluent disposal (soil backfill)	100,000	100,000
Analytical	1,120,000	470,000
Equipment repair and replacement	95,000	40,000
Site demobilization	75,000	75,000
Total cost	5,897,000	2,905,000
Cost, yd^{-3}(m^{-3})	294 (385)	145 (190)

Source: From D10061O, p. 18.
[a]Costs may vary from +50 to −30%.

Information Sources

D10061O, US EPA, January 1993

D12501Z, Ross, Remediation/Winter 1990/91

T0769

Terra Resources, Ltd.

Terra Wash Soil Washing

Abstract
Terra Wash™ is a soil washing technology that uses a combination of chemical treatment and mechanical agitation to remove contaminants from soil or to concentrate them within a smaller

TABLE 1 Vendor-Estimated Operational Costs for a 20-yd^3/hr Soil Washing System

Tons Per Hour	By Surfactant-to-Water Ratio ($)			
	H_2O Only	1:10	1:5	1:2.5
1	334.43	399.13	463.93	593.53
5	66.87	79.83	92.79	118.71
10	33.43	39.91	46.39	59.35
20	16.72	19.96	23.20	29.68
30	11.14	13.30	15.46	19.78

Source: D168290, p.12.

volume of material. According to the vendor, it is transportable for on-site use and has been used to treat drilling mud and soils contaminated with hydrocarbons and insoluble chemicals. This technology is commercially available from Terra Resources, Ltd., of Palmer, Alaska.

According to the vendor, the Terra Wash soil washing system has several advantages:

- Treats a wide variety of contaminants.
- Is a mobile system.
- Has operated in winter temperatures as low as 16°F.
- Is cost competitive with bioremediation systems.
- Has demonstrated the capability to treat fine soils.
- Operates on rough terrain and in remote sites.

All information has been supplied by the vendor and had not been independently verified.

Technology Cost

The vendor has determined that the operating costs for the Terra Wash technology depend upon the nature of the soil matrix, the contaminants treated, the rate of treatment, system maintenance requirements, and the surfactant-to-water ratio. Table 1 shows a set of vendor-estimated operational costs for a 20-yd^3/hr soil washing system. The vendor has also provided estimates for larger capacity systems; however, these larger systems have not yet been built (D168290, pp. 11–30; D21392D, p. 1).

According to the vendor, treatment costs for use of the technology on contaminated soils can be as low as $10/yd (D21392D, p. 1).

After the completion of remediation activities, 1000 to 4000 gal of fluids remain in the soil washing system. This waste requires disposal, which may cost up to $1/gal (D21392D, p. 2).

Information Sources

D168290, Lawrence D. Wood, 1997

D21392D, Wood, 1999

T0770

Terra Systems, Inc.

In Situ Bioremediation

Abstract

Terra Systems, Inc.'s, in situ bioremediation (ISB) technology can treat hydrocarbons and some chlorinated volatile organic compounds (VOCs) present in soil and groundwater. Many soils

contain indigenous microbe populations that are capable of using organic contaminants as a carbon source. The ability of a microbe population to degrade a contaminant plume is often limited by factors such as the dissolved oxygen content of the groundwater and nutrient concentrations. The ISB mixture optimizes conditions for microbial degradation.

In this patented process, extraction wells are used to create an area of hydraulic control for capturing the contaminated groundwater. Water is pumped to the surface via extraction wells, then reinjected either through infiltration galleries or injection wells outside of the plume. Before reinjection, a combination of air, hydrogen peroxide, liquid oxygen, and/or nutrients is mixed into the water to treat hydrocarbons. By adding lactate, nutrients, cultured microbes, and/or substrates to the subsurface, ISB can also be used to treat some chlorinated VOCs through reductive dechlorination.

The ISB process has been used by Terra Systems, Inc., and its predecessor company Biosystems, Inc., for treatment at many sites contaminated with hydrocarbons and VOCs. It is currently commercially available.

Although ISB can be effective at treating hydrocarbons and some VOCs, the technology has the following potential limitations:

- Injected nutrients may not be able to penetrate low-permeability formations.
- High concentrations of easily oxidized metals in groundwater can cause clogging of injections wells.
- Concentrations of gasoline components above approximately 40 ppm can cause lysis of the microbial cells and reduce the effectiveness of the biodegradation process.

Technology Cost

The cost of using ISB to remediate a 27-acre site contaminated with gasoline was approximately $1.2 million. Costs associated with project management and hydrogeological investigation were $2.2 million (D16546S, p.16). At another 2-acre site, the total cost to bioremediate 21,000 gal of gasoline was $1.16 million, or $9.21/lb of gasoline remediated (D16546S, p.37).

According to the vendor, frequent injections may be required when using soluble substrates with ISB for reductive dechlorination. As a result, capital costs can be high. The use of soluble substrates can also lead to higher operation and maintenance costs because of problems created by equipment biofouling. In contrast, ISB using edible oil substrates can result in lower capital costs. The use of edible oils can also reduce expenses associated with operation and maintenance because oil substrates reduce well clogging (D22923M, pp. 22, 23).

Information Sources

D16546S, Terra Systems, Inc., 1997
D22923M, Terra Systems, Inc., 2000

T0771

Terra Vac

DNAPL Vaporization

Abstract
Terra Vac's dense non-aqueous-phase liquid (DNAPL) vaporization involves heating the subsurface, including both groundwater and soil, to vaporize the DNAPL. According to the vendor, this technology is appropriate for medium and large sites with separate pools of dense chlorinated solvents, such as chloroform, dichloroethane, dichloroethene, Freons, methylene chloride, and vinyl chloride. This technology is commercially available.

For DNAPL vaporization to work, the soil material must be permeable enough for the vapor bubbles to rise to the top of the water table. DNAPL vaporization is not effective for some low-volatility compounds, such as dichlorobenzene, diesel fuel, naphthalene, phenol, trichlorobenzene, and trichloropropane, unless it is coupled with groundwater sparging. All information is from the vendor and has not been independently verified.

Technology Cost
According to the vendor, the cost of DNAPL vaporization is \$15 to \$45/yd^3, excluding vapor treatment (D168596).

Information Source

D168596, vendor literature

T0772

Terra Vac

Geochemical Fixation

Abstract
Geochemical fixation is a chemical treatment for selected inorganic contaminants in groundwater. It involves pumping some of the contaminated groundwater (often done in conjunction with other treatments), adjusting the pH, and adding reducing agents and/or other chemicals. The treated water is then pumped back into the groundwater layer where the added chemicals react with the contaminants and the subsurface material, resulting in fixation of the contaminants.

According to the technology developer, geochemical fixation can treat dissolved hexavalent chromium and other metals in groundwater at concentrations ranging from the detection limit to several hundred parts per million. The developer asserts that geochemical attenuation can treat most of the common heavy metals, trace elements, and natural radionuclides that occur in groundwater, such as metal–cyanide complexes, arsenic, cadmium, chromium, copper, lead, selenium, uranium, and radium.

The developer asserts that the technology optimizes geochemical interactions between contaminants and aquifer material and reduces groundwater pumpage (before cleanup completion) by 10% to 25% of the conventional pump-and-treat technology. According to the developer, geochemical fixation is most effective on groundwater containing low contaminant concentrations.

The technology is commercially available.

Technology Cost
According to the vendor, this technology provides major cost benefits relative to other technologies by significantly reducing the volume of groundwater extracted to meet remediation goals (D15817S, p. 1).

Information Source

D15817S, Terra Vac web page, 1996

T0773

Terra Vac

Heap Leaching

Abstract
The Terra Vac heap leaching technology is an ex situ hazardous remediation process that has been previously applied by the mining industry to recover gold, uranium, copper, and other

metals from low-grade ores at sites worldwide. The process is applied primarily to metal-bearing materials that biological or chemical processes cannot degrade. Terra Vac achieves cost-effective soil leaching by using a modified mining industry heap leach procedure that is used primarily to process large-volume/low-grade materials. Testing up to this point has been bench scale, and further development of the technology has been halted. This technology is not available from Terra Vac.

The heap leaching process can be used to treat contaminated soil, sludge, or solid waste. The process treats large volumes of low-concentration waste, recovering metal for recycling. The process can be used in conjunction with other processes to treat organic contaminants and can also be used as postbiological treatment.

The heap leaching technology minimizes problems that are common to conventional soil washing processes (such as solid–liquid separation) by performing the process under unsaturated conditions. When treating organic contaminants, the heap leaching process requires a separate treatment technology. The additional treatment technology minimizes interference with the metal leaching process. Additionally, multiple-metal contamination may require several leachings when the initial leach solution does not remove all metals from the treated waste.

Technology Cost

No general cost information was available for the Terra Vac heap leaching process. Terra Vac achieves cost-effective soil leaching by using a modified mining industry heap leach procedure, used primarily to process large-volume/low-grade materials (D100890, p. 2). The modified heap leaching mining method has been demonstrated at a former battery manufacturing plant near Melbourne, Australia. The vendor estimates that the method will cost approximately $30 per ton of soil treated (D121631, p. 1).

Information Sources

D100890, VISITT 4.0
D121631, Hazmat World, September 1991

T0774

Terra Vac, Inc.

Biovac

Abstract

The Biovac® technology uses the injection of oxygen and/or other nutrients for the enhancement of indigenous microorganisms for biodegradation of contaminants in soil and groundwater. According to the vendor, the commercially available, in situ technology has successfully treated soil and groundwater contaminated with benzene, toluene, ethylbenzene, xylene (BTEX); methyl ethyl ketone (MEK); methyl isobutyl ketone (MIBK); acetone; naphthalene; Freon 113; dichloroethane (DCA); trichloroethane (TCA); trichloroethene (TCE); perchloroethylene (PCE); pesticides; gasoline; jet fuel; diesel; machine shop cutting oil; and hydraulic oils.

This technology supplements the capabilities of the vapor extraction process when large numbers of nonvolatile compounds are present. Applications of this technology are usually more cost effective because remediation is conducted in situ.

The remediation site must be capable of supporting drilling operations where vapor extraction wells are required. Microorganisms used for bioremediation are not effective in toxic soil conditions. Also, because the rate of bioremediation is much slower than vapor extraction, the system must operate for a period of time after volatile contaminants have been removed by vapor

extraction. Microorganisms may need to be added to areas lacking sufficient indigenous populations. After the technology is installed, it must be continuously monitored to ensure optimum bioremediation rates.

Technology Cost
The vendor estimates the cost of remediation using the Biovac technology to be $40 to $125 per ton. Factors that influence the cost include quantity of waste, moisture content of the soil, and initial and target contaminant concentrations (D10342U, p. 30).

Information Source

D10342U, VISITT 4.0, 1995

T0775

Terra Vac

Dual Vacuum Extraction

Abstract
Terra Vac has developed Dual Vacuum Extraction™ (DVE) technology for the extraction of volatile organic compounds (VOCs) from groundwater and soil. DVE combines a soil vacuum extraction system with a groundwater recovery system. DVE wells operate below the water table and allow for extraction of VOC-contaminated groundwater and volatilization of VOCs in the soils above the water table.

Terra Vac lists the following advantages of DVE:

- Recovers residual VOCs below the static water table, where vacuum extraction cannot.
- Recovers VOCs from within the cone of depression created by pumping of the aquifer, where pump-and-treat technologies are normally ineffective.
- Increases water extraction rates in low-permeability settings.
- May eliminate the need for downhole pumps through the use of entrainment extraction in low-permeability settings.
- Reduces the cost of remediation.

DVE does not destroy contaminants; it must be used in conjunction with another remediation technology. DVE cannot remove heavy chlorinated compounds or hydrocarbons heavier than the middiesel range. DVE cannot recover pesticides or polychlorinated biphenyls (PCBs). Generally, the deeper the contaminant, the more complex extraction becomes. Problems with iron fouling have been reported at DVE sites.

Soil type and heterogeneity of the soil influence well locations and well screen intervals. As the percentage of fine grains in the soil increases, permeability decreases and water content increases. In fine-grained soils, the effective radius of treatment of DVE is reduced, meaning there is a smaller area where the vacuum is sufficient to induce in situ volatilization of hydrocarbons.

Technology Cost
In 1991, Roy cited costs at a Central Lake, Michigan, 1-acre site with an initial trichloroethylene (TCE) level of 500 ppb at $160,000. The groundwater phase of the project cost $100,000, with annual operating costs of between $15,000 and $20,000. Initial investment at a site in the Netherlands was estimated at $80,000. Monitoring costs were lower for the Netherlands site due to less stringent requirements (D12730A).

A soil vapor extraction (SVE) system, which included the Terra Vac DVE technology, was used to clean up the Tyson's Dump Superfund site in Upper Merion Township, Pennsylvania. Total remediation costs at this site were $39.9 million to treat 30,000 yd^3 of soil, or $1,330/yd^3 of soil treated. These costs included construction, operation, and maintenance expenses. The U.S. Environmental Protection Agency (EPA) notes that technology costs at this site may be high when compared to other SVE applications because of enhancements made to the system during operation (D18517V, p. 255).

At a Superfund site in Battle Creek, Michigan, DVE was used as part of a larger SVE system to treat 26,700 yd^3 of VOC-contaminated soil. Excluding before-treatment cost elements, total remediation expenses at the site were $1,645,281. This value translates to $62/yd^3 of soil treated, or $37/lb of contaminant removed. Before-treatment costs at the site equaled $535,180. The EPA notes that overall costs at this site were higher because of the extensive sampling and analysis that were required (D13945R, pp. 225, 227; D125053, p. 871).

Information Sources

D12730A, Roy, 1991

D125053, Piniewski et al., 1992

D13945R, U.S. EPA, 1995

D18517V, U.S. EPA, 1998

T0776

Terra Vac, Inc.

OxyVac

Abstract

OxyVac™ is an in situ chemical oxidation technology. This technology is used to treat soils and groundwater contaminated with volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) in the unsaturated and saturated zone and to treat dense non-aqueous-phase liquid (DNAPL) pools in the saturated zone. OxyVac is most commonly applied using hydrogen peroxide. The technology is typically used with soil vapor extraction (SVE) to prevent off-gas migration and to complete remediation activities. OxyVac has been used in full-scale cleanups and is commercially available.

According to the vendor, OxyVac has the following advantages:

- It is fast, achieving full effect within a few days.
- It can be applied with minimal site impact. It requires no piping installations or construction that might interfere with site activities. It can be applied at night, on weekends, or during other slow periods.
- The heat of oxidation can benefit other remediation techniques.
- The contamination is destroyed in situ, possibly eliminating waste generation.

After initial installation of the system (wells, manifold, and treatment system), system operation, monitoring, and maintenance are routine. The most difficult part of this technology is the proper selection of well screening intervals. If the vapor extraction well is not properly screened, air will enter the well from regions of the soil that do not contain the contaminant, leaving regions that do contain the contaminant bypassed by the airflow.

The oxidant must be injected or spread through the volume of soil that is to be treated. This may require a close spacing of injection points. The oxidant cost may be prohibitive for large

treatment volumes or for soils with high organic content. Soils with low iron content may need to be treated with iron salts.

Technology Cost

According to the vendor, the price range for this technology is \$8 to \$12 (1995 dollars) per pound of VOC treated. This price estimate does not always include indirect costs associated with treatment, such as excavation, permits, and treatment of residuals (D10341T, p. 19).

Factors that have a significant effect on unit price include the following:

- Quantity of waste
- Initial contaminant concentration
- Characteristics of soil
- Target contaminant concentration
- Moisture content of soil
- Depth of concentration
- Depth to groundwater (D10341T, p. 19)

For in situ applications, the use of OxyVac costs only 25% to 30% more than the use of soil vacuum extraction or Dual Vacuum Extraction™ alone. The added costs are mostly due to expenses associated with the hydrogen peroxide distribution system. Costs generally range from \$25 to \$100 per ton of soil treated (D21576J, p. 2).

In 1996, OxyVac was used at a cement products manufacturing site in Salt Lake City, Utah, to treat 6400 to 14,000 yd^3 of soil and sediment contaminated with VOCs. Groundwater and light non-aqueous-phase liquids (LNAPLs) were also treated to a depth of 7 to 15 ft in an area of 25,000 sft^2. Total costs at this site were \$230,000 (D10341T, p. 16; D21575I, pp. 13, 14).

A SVE system that included the Terra Vac OxyVac technology was used to clean up the Tyson's Dump Superfund site in Upper Merion Township, Pennsylvania. Total remediation costs at this site were \$39.9 million to treat 30,000 yd^3 of soil, or \$1330/yd^3 of soil treated. These costs included construction, operation, and maintenance expenses. The U.S. Environmental Protection Agency (EPA) notes that technology costs at this site may be high when compared to other SVE applications because of enhancements made to the system during operation (D18517V, pp. 249, 255).

Information Sources

D10341T, VISITT Version 4.0, 1995
D18517V, U.S. EPA, 1998
D21575I, U.S. DOE, 2000
D21576J, Environmental Business Association of New York State, undated

T0777

Terra-Vac, Inc.

Pneumatic Soil Fracturing

Abstract

The pneumatic soil fracturing (PSF) technology is a commercially available, in situ technology that increases the airflow in low-permeability soils, such as clay, thus increasing the amount of volatile organic compounds (VOCs) withdrawn by vacuum extraction. Additional flow paths are created by injecting compressed air into soil, creating fractures around the injection point.

This increases the number of advective airflow paths and the volume of soil in contact with advective airflow. According to the vendor, the PSF technology used in conjunction with Terra Vac's Dual Vapor Extraction™ has successfully remediated benzene, toluene, ethylbenzene, xylene, (BTEX), tetrachloroethylene (PCE), trichloroethylene (TCE), dichloroethylene (DCE), trichloroethane (TCA), dichlorobenzene, trichloropropane, and gasoline.

Pneumatic fracturing has several advantages:

- Reduces the number of remediation wells required to treat an area.
- Increases airflow rates in the subsurface by 400 to 700%.
- Makes in situ remediation possible at sites where excavation was previously the only option.
- Minimizes site or property disturbances.

Pneumatic soil fracturing is not a treatment technology. It must be combined with a treatment technology to remediate a site. The final location of new fractures is uncontrollable. The fractures may open new pathways for the unwanted spread of contaminants. After fracturing pockets of low permeability will remain. In nonclayey soils, the fractures will close. The technology is not applicable at sites with high natural permeabilities or levels of seismic activity. A PFS site must be capable of supporting the drilling operations for extraction wells. The investigation of underground utilities, structures, or trapped free product is required.

Technology Cost

The vendor claims that PSF technology was used to treat 400 ft^2 of soil contaminated with trichloroethene (TCE) to a depth of 4 to 12 ft for a cost of $500,000. At another site, 10,000 sft^2 of soil contaminated with tetrachloroethene (PCE), TCE, and trichloroethane (TCA) was treated to a depth of 15 ft for a cost of $200,000 (D10339Z, pp. 13–16).

A study performed by the U.S. Department of Energy (DOE) stated that fracturing technologies are particularly cost effective at contaminated sites with low-permeability soil and geologic media, such as clays, shales, and tight sandstones where remediation without some sort of permeability enhancement is difficult or impossible. However, the usefulness of fracturing technologies is not limited to low-permeability sites. Furthermore, fracturing does not add significant up-front costs (up to a few percent) to an overall remediation system and may provide significant reduction in the life-cycle costs to remediate a site because fewer wells may be required and cleanup may be accomplished more rapidly (D183771, p. 1). The costs for pneumatic fracturing were estimated to range from $9 to $13 per metric ton (D20737E, p. 2).

Information Sources

D10339Z, VISITT 4.0, 1995

D183771, U.S. DOE, 1998

D20737E, Construction and Engineering Management, Purdue University, 2000

T0778

Terra Vac, Inc.

Sparge VAC

Abstract

The Sparge VAC™ system is an integrated vacuum extraction (VE) and groundwater sparging (GWS) technology. This technology remediates soil and groundwater contaminated with volatile

organic compounds (VOCs) in situ. According to the vendor, the Sparge VAC system acts as an in situ air stripping system. Air or a carrier gas such as nitrogen gas is injected into the saturated zone of the contaminated groundwater plume. The gas rises through the plume, causing the contaminants to volatilize. It then passes into the vadose zone of the soil and is removed using VE technology.

The technology has been used in full-scale field applications and is commercially available. According to the vendor, Sparge VAC technology offers the following advantages:

- Requires no above-ground discharge of water.
- Does not require draining the aquifer, reducing treatment costs.
- Can add oxygen to saturated zone, increasing biodegradation rates.
- Partitions volatile and semivolatile organic compounds.

The site must be capable of supporting drilling operations in the locations where the VE and air sparging wells are desired. In some cases, horizontal drilling may be required to avoid drilling through buildings or other existing features of the site. This technology will perform correctly only on volatile or semivolatile contaminants. Contaminants that form complexes with the soil matrix are not effectively remediated using this technology. Some soil or rock structures are not conducive to this type of treatment. For example, a layer of low-permeability soil overlying the saturated zone may prevent the injected air from being scavenged by the VE system installed above it.

Technology Cost

The estimated price for this technology is approximately $15 to $90 (1995 dollars) per cubic yard of waste treated. This estimate does not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals.

Factors that have a significant effect on unit prices include the following:

- Quantity of waste
- Soil stratigraphy
- Initial contaminant concentration
- Target contaminant concentration
- Depth of concentration
- Depth to groundwater
- Characteristics of soil
- Amount of debris with waste (D10343V, p. 20)

Information Source

D10343V, VISITT Version 4.0, 1995

T0779

Terra Vac, Inc.

Vacuum Extraction

Abstract

The Terra Vac vacuum extraction process is a patented, in situ process used to remove volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) from contaminated

soils. The process is a type of soil vapor extraction (SVE) technology that uses wells to extract soil gas containing VOCs and SVOCs such as those found in solvents and fuel components. Vacuum extraction exerts negative pressure to the subsurface soils, inducing airflow toward the extraction well. The extracted contaminant stream passes through a vapor–liquid separator and the resulting off gases undergo treatment before being released to the atmosphere.

Depending on the depth of the soil being remediated, a vacuum extraction system may be connected to vertical or horizontal extraction wells. As air flows through the soil pore spaces, the contaminants are volatilized in place and driven toward the extraction wells. Contaminants are then recovered and treated at the surface, usually by activated carbon, catalytic oxidation, or thermal treatment.

According to the vendor, the following advantages have been associated with this technology:

- Minimal site disturbance
- Capable of rapid site cleanup
- Most widely used innovative remedial technology

Vacuum extraction alone is limited to treating unsaturated soils, and successful remediation is contingent upon factors such as soil properties and the volatility of the contaminants. Ideally, measured soil permeabilities should range between 10^{-4} and 10^{-8} cm/sec, and contaminants should have a Henry's constant of 0.001 or higher. Also, sites with complex stratigraphy or contaminant distributions may require pilot demonstrations prior to the full implementation of a vacuum extraction system.

Technology Cost

The costs associated with the Terra Vac vacuum extraction process depend on whether off-gas treatment is required and whether any wastewater is generated at a site. Treatment of wastewater can add as much as 20% to the total cost. The vendor claims that treatment costs are typically near $50 per ton, but for a large remediation project, when no off-gas treatment is generated, the remediation cost can be less than $10 per ton (D12629E, p. 824; D125031, p. 63).

A SVE system that used the Terra Vac vacuum extraction technology was used to clean up the Tyson's Dump Superfund site in Upper Merion Township, Pennsylvania. Total remediation costs at this site were $39.9 million to treat 30,000 yd^3 of soil, or $1330/$yd^3$ of soil treated. These costs included construction, operation, and maintenance expenses. Technology costs at this site may be high when compared to other SVE applications because of enhancements made to the system during operation (D18517V, p. 255).

Since SVE does not destroy contaminants, it is most commonly used in a treatment train with other technologies, such as granular activated carbon (GAC), thermal oxidation technologies, or scrubbing. Other technologies, including bioremediation, natural attenuation, air sparging, or fracturing, may be used to either increase the efficiency of SVE technology or treat residual contamination that may remain after SVE is used at a site. All of these factors will impact treatment costs (D22449H, p. 4–1).

Many factors can influence the cost of SVE treatment. Soil properties that can influence SVE costs include permeability, porosity, depth and stratigraphy of the contamination, site heterogeneity, and seasonal water table fluctuations. In general, the more permeable and homogenous the soil, the more efficiently SVE will operate and the lower treatment costs will be (D22449H, p. 4–4).

Contaminant properties can also affect treatment costs. The type and amount of contaminants will impact the efficiency of SVE, the number of extraction wells, the power of the blower unit, and the length of operation required to achieve project goals. It will also impact the type of ancillary technology(ies) selected (D22449H, p. 4–4).

In 2001, the U.S. Environmental Protection Agency (EPA) published a cost analysis of various remediation technologies, including SVE. SVE technology costs were analyzed based on operation and maintenance (O&M) costs, capital costs, and other site-specific data (D22449H, p. 4–1).

In the cost analysis, the EPA stated that there was a correlation between SVE unit costs and the volume of soil treated. SVE was demonstrated to have a measurable economy of scale. Unit costs for the treatment of less than 10,000 yd^3 of soil ranged from \$60 to \$350/yd^3. Unit costs for applications treating more than 10,000 yd^3 of soil were as low as \$5/yd^3 treated. A similar correlation was noted for unit costs versus mass of contaminants removed. Unit costs for projects with less than 3000 lb of contaminants requiring removal ranged from \$300 to \$900/lb. Unit costs for larger projects were less than \$15/lb, and costs for treating over 500,000 lb of contaminant were less than \$2/lb (D22449H, pp. 4–1, 4–4).

Information Sources

D12629E, James Malot and Roman Bober, date unknown

D125031, Federal Remediation Technologies Roundtable, May 1991

D18517V, U.S. EPA, 1998

D22449H, U.S. EPA, 2001

T0780

Terra Vac

Soil Heating

Abstract

Soil heating is an in situ technology that is designed with vacuum extraction to increase the vapor pressure of semi- and nonvolatile contaminants, thereby increasing the effectiveness of vacuum extraction. According to the vendor, for a given contaminant concentration in the soil, heating the formation to about 70°C will increase the amount of contaminant vapor concentration by a factor of 16. According to the vendor, this process can be implemented through hot and humid air injection, steam injection, electric soil heating, radio frequency heating, and oxidant injection. Each method is commercially available for site remediation.

The vendor claims the following advantages for the technology:

- Increased contaminant volatility
- Faster soil desiccation
- Faster vapor diffusion
- Enhancement of soil microbe populations

All information is from the vendor and has not been independently verified.

Technology Cost

The following cost information is provided by the vendor and has not been independently verified.

A 4-month vapor extraction project in which the soil was heated to 160°F would require approximately 200,000 Btu/yd^3. According to the vendor, the energy cost for electricity-provided heat would be about \$6.00/yd^3. For natural gas and propane, the cost would be lowered to \$1.00 and \$1.60/yd, respectively (D15838X, p. 2).

The installation cost of a hot-air injection system including stainless steel wells is about \$15,000 to \$22,000 for a 50-kW system. The electricity would cost about \$3600 per month. These costs do not include the vapor extraction portion of the system.

The total installation cost for a 200-kW steam injection system would be about \$35,000 to \$45,000. The natural gas and treated water cost would be about \$7500 per month.

The installation cost for a humid air injection system varies from about $15,000 for a 50-kW plastic pipe system to about $45,000 for a 200-kW high-temperature system. The operating costs would be about $3600 and $8000 per month, respectively.

The operating cost of Electro VAC can be significantly higher than other soil heating systems that use fuel heating, electrical heating costs about seven times more than fuel heating.

The high costs of using radio frequency heating limit its use to very expensive remediation projects that require a unique heating method (D15838X, pp. 2–9).

Information Source

D15838X, Beyke, 1994

T0781

Terrafix, LLC

Terrafix

Abstract

Terrafix is a transportable ex situ technology that uses screening, magnetic separation, and chemical/cementitious material for removal and fixation of metal wastes in soils or sludges. Terrafix is a commercially available technology that has been used to treat over four million tons of wastes and soils on a full-scale level.

Terrafix units are trailer-mounted, fully transportable units that can be operational within hours after arrival at the site. The units are designed to screen out large material such as rocks and metal parts as well as remove ferrous material using magnetic separation. The remaining material is then mixed in a pug mill with cementitious materials (i.e., cement, fly ash, pozzilime) and/or silicates to produce a material in which the heavy metals are chemically fixed.

All information was supplied by the vendor and could not be independently verified.

Technology Cost

No available information.

T0782

Terra-Kleen Response Group, Inc.

Terra-Kleen Solvent Extraction Technology

Abstract

The Terra-Kleen solvent extraction technology is an on-site, batch-process system that uses a proprietary solvent to remove hazardous organic constituents from soils. The treatment system uses a solvent regeneration system that concentrates the extracted contaminants and then recycles the extraction solvent. The treated soil can often be returned to the site. The concentrated contaminants are usually transported off-site for disposal.

The technology has been used in full-scale applications and is commercially available.

According to the vendor, the Terra-Kleen solvent extraction technology has several advantages:

- Is easily mobilized and requires minimal site preparation.
- Treats a variety of organic compounds in soils.

- Operates as a closed-loop system.
- Achieves clean-up objectives in a short amount of time.
- Uses a nonhazardous solvent.
- Reduces the volume of contaminated material requiring disposal.

Several conditions that would decrease the effectiveness of the Terra-Kleen solvent extraction technology are:

- Soil containing more than 20% clays or fines where contaminants are strongly sorbed
- Soils containing more than 20% moisture content
- Cold climates

Technology Cost

Cost Estimates In 1994, the Terra-Kleen solvent extraction technology was demonstrated at the U.S. Department of Defense's (DOD's) Naval Air Station North Island Site 4 as part of the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) demonstration program. In 1998, the EPA prepared a cost estimate based on this demonstration (D20809D, pp. 36–41; D107448). This estimate is presented in Table 1.

The DOD's Navy Environmental Leadership Program (NELP) estimated that the costs of using the Terra-Kleen solvent extraction technology to treat 1 ton of soil contaminated with polychlorinated biphenyls (PCBs) would range from \$165 to \$600. This estimate included capital costs, mobilization and demobilization costs, and operational and maintenance (O&M) costs. The NELP stated that treatment costs will vary based on the contaminant, contaminant concentration, and total volume of soil to be treated. According to NELP, the Terra-Keen technology presents an effective alternative PCB treatment. The technology is comparable to estimated landfill disposal costs of \$200 to \$300 per ton but more cost-effective than incineration costs of \$2000 to \$4000 per ton (D12493G, p. 4).

The vendor estimated that the treatment costs for the Terra-Kleen solvent extraction technology range from \$120 to \$800 per ton. Treatment costs vary based on the initial and target contaminant concentrations, quantity of waste to be treated, characteristics of the residual waste,

TABLE 1 Cost Estimate Based on the Superfund Innovative Technology Evaluation (SITE) Program Demonstration (in 1995 Dollars)

	Cost Per Volume of Soil Treated		
Cost Category	500 yd^3	2,000 yd^3	10,000 yd^3
Site preparation	19,160	19,160	19,160
Start-up	25,120	61,120	253,120
Equipment	56,375	101,190	232,320
Labor	45,920	183,680	918,400
Consumables and supplies	32,250	129,000	645,000
Utilities	380	1,520	7,630
Effluent treatment and disposal	20,000	80,000	400,000
Residual and waste shipping and handling	4,700	15,000	43,800
Analytical services	9,000	36,000	180,000
Demobilization	11,050	11,050	11,050
Total cost	223,955	637,720	2,710,480
Unit cost per ton of soil treated	300	210	170

Source: Adapted from D20809D.

soil characteristics, labor rates, moisture content of the soil, utility and fuel rates, site preparation, and amount of debris in the waste stream (D22658O, p. 5).

Demonstrated Costs The Terra-Kleen solvent extraction technology was used at the Sparrevohn Long Range Radar Station (LRRS) in Alaska to treat 288 yd^3 of soil contaminated with PCBs. The total cost of the project was $828,179. Approximately $225,649 was attributed to activities directly related to soil treatment. This represents a unit treatment cost of $780/$yd^3$ of soil treated. The remaining $602,530 was spent on mobilization and demobilization. These costs were relatively high because the site was only accessible by air. According to a DOD cost analysis, solvent extraction cost less than 50% as much as off-site disposal, which was estimated at $1.9 million (D19500Q, pp. 60–61).

A full-scale remediation using the Terra-Kleen solvent extraction technology was conducted in 1994 at the naval communications station in Stockton, California. Approximately 550 tons of soil was contaminated with chlorinated pesticides. According to the vendor, treatment costs for this application were $400 per ton of soil treated (D10344W, pp. 15–16; D20809D, p. 46).

The technology was used at the Cape Canaveral Air Station in Florida to treat 10,000 tons of soil contaminated with PCBs and trichloroethene (TCE). The vendor states that the cost of this full-scale application was less than $120 per ton (D22659P, p. 6).

According to the vendor, the technology treated 10,000 tons of soil contaminated with PCBs from an industrial landfill at the Naval Air Station North Island in Coronado, California. The total cost for this project was $1,100,000. The vendor states that the unit costs were $145 per ton (D22658O, p. 8).

Information Sources

D10344W, VISITT, 1996

D107448, U.S. EPA, 1995

D12493G, Navy Environmental Leadership Program, 1995

D19500Q, U.S. Army Corps of Engineers, 1998

D197095, Navy Environmental Leadership Program, 1996

D20809D, U.S. EPA, 1998

D22658O, U.S. EPA Reachit, undated

D22659P, Terra-Kleen Response Group, Inc., undated

T0783

Terrapure Systems, L.L.C.

Palladized Iron Remediation Technology

Abstract

Terrapure Systems, L.L.C. (Terrapure), is currently developing palladized iron remediation technology (PIRT). The deposition of small amounts of palladium (approximately 0.05 wt%) on the surface of iron particles may result in a bimetallic surface that can cause the dechlorination of aqueous organic compounds. The developers claim that the technology can be used as an in situ or ex situ process and can be applied to aqueous contaminants and soil. PIRT has been evaluated in bench-scale tests and is not currently commercially available.

Terrapure claims that PIRT will completely dechlorinate chlorinated organic compounds, can be used as an in situ or ex situ technology, and is more effective than competing technologies.

In the patent application, Terrapure states that the technology is most applicable to treated chlorinated organic contaminants present in concentrations ranging from 5 to about 200 ppm.

Technology Cost
No available information.

T0784

TerraTherm Environmental Services, Inc.

Thermal Blanket for In Situ Thermal Desorption

Abstract
TerraTherm Environmental Services, Inc., a subsidiary of Shell Technology Ventures, Inc., has developed the in situ thermal desorption (ISTD) thermal blanket technology to treat or remove volatile and semivolatile contaminants from near-surface soils and pavements. The contaminant removal is accomplished by heating the soil in situ (without excavation) to desorb and treat contaminants. In addition to evaporation and volatilization, contaminants are removed by several mechanisms, including steam distillation, pyrolysis, oxidation, and other chemical reactions. Vaporized contaminants are drawn to the surface by vacuum, collected beneath an impermeable sheet, and routed to a vapor treatment system where contaminants are thermally oxidized or adsorbed.

Thermal blankets have been used in full-scale site remediation, and the technology is commercially available. Thermal blankets are often used in conjunction with a related technology called thermal wells for in situ thermal desorption. The thermal well technology is also discussed in the RIMS 2000 library/database.

The technology can be used in any type of soil, including low-permeability clays. According to the vendor, this technology can be used to treat polychlorinated biphenyls (PCBs), dioxins, chlorinated solvents, pesticides, and herbicides. The thermal blanket technology has been demonstrated to remediate PCB-contaminated soil to a level of 2 ppm.

The thermal blanket technology does have several limitations. High soil moisture increases the cost of remediation involving thermal desorption because of the energy required to vaporize the water. In addition, treatment within the saturated zone is not feasible since treatment temperatures would be limited to the boiling point of water (i.e., 100°C). Finally, the technology is only effective to an approximate depth of 0.5 m below ground surface.

Technology Cost
According to the vendor, in situ thermal desorption technologies (either thermal blanket or thermal wells) are less costly than alternate methods, such as excavation and removal of the soil (D142609, p.1). Based on a field demonstration in Cape Girardeau, Missouri, the vendor claims that a full-scale application should cost between \$120 and \$200/yd^3 of soil (D18515T, p.280). However, Looney and Falta note that thermal wells and thermal blankets are "equipment- and power-intensive," making these technologies relatively expensive (D21457D, p. 989).

Estimates based on pilot-scale test results indicate that commercial soil treatment at a large site (15 acres) to a depth of 15 cm will cost in the range from approximately \$45 to \$60/m^2 or \$150 to \$200 per metric ton of soil (excluding profit and royalties and with capital equipment costs amortized over a 5-year period) (D14256D, p. 3154). The cost components included in this estimate are about evenly split among labor; utilities, including electric; and equipment (materials and depreciation). It is assumed that the system would remediate 3200 sft^2 per day using two blanket assemblies, each made up of 20 modules that are 8 ft by 20 ft. Each module would be powered by a maximum of 20 kW; the total power requirement for a 20-blanket assembly would be 1.8 million watts (D14256D, p. 3153).

Pilot tests are needed at each site to confirm cost assumptions. Factors that affect cost include soil moisture, depth of contamination, desired cleanup level, and types of contaminants present.

Energy cost to accomplish the remediation rises with the amount of water that must be vaporized from the treatment zone.

Information Sources

D14256D, Iben et al., 1996
D142609, Houston Business Journal, 1996
D18515T, Federal Remediation Technologies Roundtable, 1998
D21457D, Looney and Falta, 2000

T0785

TerraTherm Environmental Services, Inc.

Thermal Wells for In Situ Thermal Desorption

Abstract
TerraTherm Environmental Services, Inc., a subsidiary of Shell Technology Ventures, Inc., has developed an in situ thermal desorption (ISTD) technology using thermal wells to treat organic contaminants in deep soils. The technology involves heating soils in situ to desorb and destroy contaminants. In addition to volatilization, contaminants are removed by mechanisms including steam distillation, pyrolysis, oxidation, and other chemical reactions. This technology is potentially applicable to any contaminant that is volatile at the treatment temperature or that can be pyrolyzed or oxidized to form volatile products.

Vapors released by heating are drawn to the surface by vacuum extraction and routed to a vapor treatment system where they are destroyed in a flameless thermal oxidizer. According to the vendor, thermal wells can remediate contamination at depths previously thought to be unreachable and/or untreatable.

Thermal wells have been used in full-scale site remediation, and the technology is commercially available. For near-surface remediation, thermal wells are often used in tandem with a related technology called thermal blanket. The thermal blanket technology is also discussed in the RIMS 2000 library/database.

According to the vendor, thermal wells:

- Treat a wide range of contaminants in soil compositions of varying permeability, water content, and depth.
- Exhibit high removal efficiency and are cost effective compared to traditional ex situ methods.
- Treat a contaminated area of any size, above or below the water table.
- Require no long-term operation or management.
- Increase desorption and contaminant removal.
- Result in benign products such as carbon dioxide and water.
- Minimize potential exposure and yield no contaminated material requiring disposal.
- Can be installed vertically, on an angle, or horizontally.

Limitations of this technology include the following:

- Treatment of soils below the water table may not be feasible due to power requirements and difficulty attaining high temperatures deep in the subsurface.
- Heating may alter certain soil properties, such as permeability and plasticity.

Technology Cost

According to the vendor, in situ thermal desorption technologies (either thermal Blanket or thermal wells) are less costly than alternate methods, such as excavation and removal of the soil (D142609, p. 1). Based on a field demonstration in Cape Girardeau, Missouri, the vendor claims that a full-scale application should cost between \$120 and \$200/yd^3 of soil (D18515T, p. 280). However, Looney and Falta note that thermal wells and thermal blankets are "equipment- and power-intensive," making these technologies relatively expensive (D21457D, p. 989).

For thermal wells, the deeper the wells, the lower the cost per ton of soil treated. This is because the incremental cost of drilling deeper and delivering power deeper is small. A deeper well can also treat a larger volume of soil. Therefore, the price per ton decreases dramatically (personal communication, Jude Rolfes, President, TerraTherm, February 1997).

Information Sources

D142609, Houston Business Journal, 1996

D18515T, Federal Remediation Technologies Roundtable, 1998

D21457D, Looney and Falta, 2000

T0786

Teton Technologies, Inc.

In Situ Waste Destruction and Vitrification

Abstract

Teton Technologies (Teton) has developed the in situ waste destruction and vitrification (IWDV) process for the treatment of hazardous wastes. The process uses a graphite arc melter system that is lowered into a previously installed borehole that penetrates through the zone of contamination. The arc melter is activated at the bottom of the borehole and slowly withdrawn upward through the contaminated material. The heat from the arc melter destroys organic contaminants and melts inorganic material. The molten material cools to form a glassy, leach-resistant monolith. The technology has been evaluated on a pilot-scale basis.

The vendor claims that the IWDV process is uniquely applicable to virtually all types of buried wastes, including organic compounds, hazardous metals, and radionuclides. The bottom-up method of vitrification reduces the risk of an explosion during treatment. The electrode system requires no cooling water and operates at near 100% efficiency.

Mercury or cadmium in the contaminated material may be volatilized during treatment and therefore would have to be captured by the off-gas treatment system. If mercury or cadmium is present in the off-gas waste, it will be captured in a scrubber solution that would then require drying and stabilization prior to disposal at a landfill licensed under Resource Conservation and Recovery Act (RCRA) criteria.

Technology Cost

No available information.

T0787

Texaco, Inc.

Texaco Gasification Process

Abstract

The Texaco gasification process (TGP) is a patented ex situ commercial technology for the treatment of hazardous and nonhazardous liquid or solid waste. The high-temperature, high-pressure, partial-oxidation technology is designed to destroy organic contaminants and immobilize metals while producing a usable synthesis gas product consisting of roughly 37% hydrogen, 36% carbon monoxide, and 21% carbon dioxide.

Waste gasification is an innovative extension of Texaco's conventional fuels gasification technology that reacts carbonaceous materials with a limited amount of oxygen (partial oxidation) at high temperatures. Given its ability to deal with a variety of feedstocks, destroy organic compounds, produce a useful synthesis gas, and solidify inorganic compounds into potentially inert glassy slag, the TGP offers an effective treatment alternative for hazardous wastes.

The TGP can process a variety of waste streams. Virtually any carbonaceous, hazardous, or nonhazardous waste stream can be processed in the TGP if the pretreatment facilities for storage, grinding, screening, and slurrying are adequate to handle and treat the incoming material. The waste stream may need to be supplemented with high-Btu (British thermal unit) fuel, such as coal or petroleum coke, to increase its heating value sufficiently to maintain gasifier temperatures.

The TGP has been used to gasify conventional fuels such as natural gas, liquid petroleum fractions, coal, and petroleum coke for approximately 45 years. More than 67 gasification plants were either operational or under development worldwide in 1999.

Technology Cost

Table 1 summarizes the costs, as of 1995, associated with treating 100,000 tons (90,700 metric tons) of contaminated soil using the TGP. Costs are given for a transportable TGP unit capable

TABLE 1 Treatment Costs[a] Associated with the TGP in 1995

Unit	On-site TGP		Central TGP	
Soil, tons/day (metric tons/day) design	100	(91)	200	(181)
Soil, tons/year (metric tons/year) actual	29,200	(26,500)	58,400	(53,000)
Online utilization factor, %	80	—	80	—
Years online, each site	3.42	—	15	—
Capital, $ million	11.0	—	22.0	—
Cost categories[a]	$/ton	$/metric ton	$/ton	$/metric ton
Site preparation	—	—	—	—
Permitting/regulatory	—	—	—	—
Capital equipment	$64.26	$70.83	$44.01	$48.51
Start-up	$25.00	$27.56	$0.00	$0.00
Labor	$52.60	$57.98	$26.30	$28.99
Consumables and supplies	$54.60	$60.19	$54.60	$60.19
Oxygen	$5.00	$5.51	$5.00	$5.51
Chemicals	$15.56	$17.15	$15.56	$17.15
Coal	$2.00	$2.20	$2.00	$2.20
Lime				
Utilities	$6.81	$7.51	$6.81	$7.51
Effluent treatment/disposal	$65.80	$72.53	$65.80	$72.53
Residuals	$2.74	$3.02	$2.74	$3.02
Slag	[$7.24]	[$7.98]	[$14.48]	[$15.96]
Syngas (profit; subtracted from cost)				
Analytical services	$5.00	$5.51	$5.00	$5.51
Maintenance	$11.30	$12.46	$11.30	$12.46
Demobilization	$5.00	$5.51	$0.00	$0.00
Total	$308.43	$339.98	$224.64	$247.52

Source: From D10958K, p. 48.
[a]Costs may vary by +50% to −30%.

of processing 100 tons (91 metric tons) per day of waste soil and for a stationary, centralized TGP facility designed to process 200 tons (181 metric tons) per day of waste soil. Costs for transporting waste to the centralized facility were not included (D10958K).

The transportable gasification unit is designed for a 15-year service life and is assumed to operate for about 4 years at each of three sites. For such a large and complex unit, relocation costs are high; a more practical investment may be constructing and operating a stationary unit at a central facility for the equipment's entire service life of 15 to 30 years (D10958K, pp. 47, 51).

Total costs may be reduced by charging "gate fees" for the acceptance of mixed plastic waste or municipal solid waste as feedstock or from the sale of treatment products such as the syngas or ammonium chloride (D19926C, p. 17; D199013, p. 3; D10958K, pp. 47, 51).

Costs, as of 1993, associated with a 255-MW plant located in the U.S. Gulf Coast are given in Tables 2 and 3. It is important to note that these cost estimates are using coal as fuel, not wastes (D170207).

In 1994, Texaco planned to build a $75 million TGP plant in El Dorado, Kansas. The facility opened in 1996 (D19928E, p. 1; personal communication, Francis Fong, Texaco, Inc., November 1996).

TABLE 2 1993 Gasification Plant Cost Summary (Using Pittsburgh #8 Coal for Fuel)

Site	U.S. Gulf Coast
Net output	255 MW
Heat rate at 90°F (HHV)	8400 Btu/kWh
Project costs ($1000)	
Direct field costs	$270,703
Indirect field costs	$27,476
Total Field Costs	$298,179
Office costs	$34,167
Contingency	$34,958
Total Project Costs	$367,304
($367/MW)	
($1439/kW)	

Source: From D170207.

TABLE 3 Operating and Maintenance Costs for Gasification Plant

Total Fixed Costs[a]	$89,240/week[b]
Variable Operating Costs (mills/kWh)	
Maintenance and materials	1.63
Catalyst and chemicals	0.27
Start-up costs	0.01
Cost of coal (at $30/dry ton)	9.31
Cost of back-up fuel	0.78
Sulfur credit (at $90/long ton)	0.64
Total	13.80

Source: From D170207.

[a] Includes overhead, operations, maintenance, oxygen plant staffing.

[b] Equivalent to 2.44 mills/kWh, assuming 85% capacity factor.

Information Sources

D10958K, U.S. EPA, July 1995
D170207, Texaco Gasification Update, vendor literature, 1993
D199013, Banerjee, date unknown
D19926C, Curran and Tubergen, 1996
D19928E, Texaco, 1994

T0788

Texas A&M University

Low-Pressure Surface Wave Plasma Reactor

Abstract
Texas A&M University is researching using a low-pressure surface wave plasma reactor for the treatment of gaseous waste streams containing organic contaminants. This ex situ technology can use radio or microwave frequencies to generate a low-temperature plasma. The plasma is designed to generate radicals that oxidize organic molecules. The technology has been evaluated in bench-scale tests and is not commercially available.

Researchers claim that generating a plasma using a high-frequency power source generally leads to a plasma that is easier to handle, more efficient, and less expensive than plasmas generated by direct current (DC) power sources.

No information is available on the limitations of the technology.

Technology Cost
No available information.

T0789

Texilla Environmental, Inc.

Synthetic Mineral Immobilization Technology

Abstract
Texilla Environmental, Inc. (Texilla), has developed the synthetic mineral immobilization technology (SMITE) for the stabilization of incinerator ash and other wastes containing heavy metals. The technology immobilizes hazardous inorganic material in one of several synthetic minerals collectively known as Xtaltite. Xtaltite has the form of naturally occurring minerals, typically apatite and pyrochlore. Processing involves a combination of a mixing stage where the wastes are combined with contaminant-specific additives and a thermal processing stage that produces a leach-resistant final waste form. According to the vendor, the technology is commercially available.

The vendor claims the following advantages of SMITE:

- Achieves high waste loadings (greater than 20% waste metal or 50% incinerator ash).
- Allows for treatment of a wide range of toxic metals.
- Allows for treatment with traditional stabilization and solidification equipment.
- Offers cost advantages when compared to other stabilization alternatives (2 to 5 times less expensive than conventional methods of solidification or stabilization).

The process is designed for the treatment of solid, inorganic materials. The final waste form will leach in acidic solutions, so storage in a basic environment is recommended.

Technology Cost
No available information.

T0790

Textron, Inc.

Electro-Hydraulic Scabbling

Abstract
The electro-hydraulic scabbling (EHS) technology is designed to remediate concrete deeply contaminated with radionuclides, hazardous heavy metals, and/or organic substances. Scabbling, which is the physical removal of the concrete surface layer, subdivides the mass of the concrete structure into (1) contaminated rubble of relatively small volume and (2) the remaining clean concrete structure, which can be either reused or decommissioned by regular demolition techniques. This technology remediates floors, walls, and ceilings of massive concrete structures while generating minimal secondary waste.

In September 1998, the U.S. Department of Energy (DOE) stated that, while the technology was not yet ready for industrial-scale concrete decontamination, the vendor believed that the necessary improvements to the system were relatively straightforward.

The following benefits are claimed for this technology:

- Reduction of waste volume subject to regulated disposal
- Reduction of disposal and labor costs compared with existing technologies
- Reduction of health and environmental hazards associated with decontamination and demolition processes

Material removed during scabbling will require further treatment prior to disposal.

Technology Cost
According to the vendor, equipment costs for the EHS prototype unit are estimated at \$120,000. Operating costs including consumables, maintenance, capital, and labor are estimated at \$5 to \$10/ft^2 of treated concrete (D162209, p. 9).

Information Source

D162209, Goldfarb and Gannon, date unknown

T0791

The Chlorine Institute, Inc.

Thermal Desorption (Mercury Contamination)

Abstract
The Chlorine Institute, Inc., thermal desorption process is an ex situ technology that thermally treats mercury-containing wastes. The technology produces a nontoxic ash or residue, removes

contaminants from the off gas, and recovers mercury for recycling from industrial waste, thereby eliminating the production of hazardous waste.

This technology is currently commercially available.

The process will not accommodate mixed or radioactive wastes. There may be limitations on the amount of other toxic heavy metals present in the waste.

Technology Cost

Based on data from a pilot-scale demonstration of this technology, capital costs for such a facility can vary depending on many factors such as size, location, required utilities, etc. It is believed that for a facility to handle from 2 to 20 tons of waste material per day would cost about $5 million (1992 dollars). The cost of this demonstration was approximately $3.5 million (1992 dollars) (D13741H).

Information Source

D13741H, Dungan, 1992

T0792

The Westford Chemical Corporation

BioSolve

Abstract

BioSolve® is a commercially available biodegradable surfactant that is used to enhance bioremediation of petroleum hydrocarbons in soil and water. According to the vendor, BioSolve emulsifies and encapsulates petroleum-based products so that they become nonflammable and more readily bioavailable. Bioavailability is the combination substrate availability and substrate transport that allows for the initiation of bioremediation.

BioSolve emulsifies and separates long hydrocarbon chains and encapsulates them in an oxygen-bearing solution that can result in accelerated bioremediation. In addition, since BioSolve encapsulates as well as disperses hydrocarbons, it is used as a vapor-suppressing agent and to reduce the evaporation of contaminants.

The vendor states that BioSolve technology:

- Strips the sorbed hydrocarbon phase from soil particle surfaces, enabling rapid biodegradation.
- Can be applied to in situ or ex situ processes.
- Increases the dispersal of agents that promote bioremediation.
- Acts as a food source and is biodegradable.

BioSolve itself does not cause or catalyze specific chemical reactions or contain bacterial cultures. While surfactants may speed up the process of biodegradation, any easily biodegradable compound will eventually de degraded to nondetectable limits whether or not surfactants are used.

Technology Cost

The vendor has provided information for two sites where bioremediation was attempted in combination with BioSolve surfactant in 1995. At the Sycamore Pit site, the total cost of BioSolve surfactant used was $1800; this averages approximately $9.00/yd^3 of soil treated. The total cost of remediation at the site was $7800, approximately $39.00/yd^3 of soil treated. At the Tiner Pit site, the cost of BioSolve surfactant was $4050, approximately $3.08/yd^3 of soil treated.

The total cost of remediation at the site was $16,000, approximately $12.18/yd^3 of soil treated (D171017, p. 1).

A vendor of BioSolve technology states that the contaminant type and concentration, the amount of soil to be treated, and other site conditions will impact treatment costs (D171017, p. 1). Documents provided by the vendor indicate that the total cost of bioremediation using BioSolve can range from $25 to $90/yd^3 of soil treated (D14680P, p. 93). Subsequent communication from the vendor stated that for remediation applications the cost of BioSolve was $1 to $5/yd^3 of soil treated (personal communication, Jim Figueira, Western States BioSolve, October 1997).

A cost comparison conducted in 1993 found bioremediation to cost about 25 to 50% less than thermal extraction based on historical cost statistics (D14680P, p. 127).

Information Sources

D14680P, The Westford Chemical Corporation, date unknown

D171017, undated vendor literature

T0793

Thermo Conversion Corporation

Plasma Energy Recycle and Conversion

Abstract

The plasma energy recycle and conversion (PERC) process is an indirectly heated ex situ thermal recycling and conversion technology. According to the vendor, it treats hazardous waste, mixed radioactive waste, medical waste, municipal solid waste, radioactive waste, environmental restoration wastes, and incinerator ash in gaseous, liquid, slurry, or solid form. The technology uses an induction-coupled plasma (ICP) torch as its heat source coupled to a reaction chamber system to destroy hazardous materials.

The vendor claims the following benefits for the technology:

- Very high plasma temperatures for rapid reactions and vitrification
- Flexibility regarding choice of plasma gas used in the process (argon, nitrogen, oxygen, air, steam)
- Flexibility regarding the mode of chemical reaction (oxidizing, reducing, steam reforming, cracking)
- Absolute minimization of secondary waste and conversion of the organic fraction into fuel gas
- Electrodeless plasma system requiring no replacement of parts and minimal maintenance

All information is from the vendor and has not been independently verified.

Technology Cost

According to the vendor, the cost of the PERC technology may be different for each customer and is dependent on the following factors:

- Waste type and characteristics
- Waste feed rate and processing specifics
- Mobility/transportability
- System specifics (co-generation, feed storage and preparation, etc.)
- Buildings and infrastructure

The vendor claims that a PERC system typically costs between $200,000 and $1,000,000 for a test unit and between $500,000 and over $20,000,000 for a large processing facility (D160112, p. 3).

Information Source

D160112, Plasma Technology, Inc., of Santa Fe, 1997

T0794

Thermal Desorption — General

Abstract
Thermal desorption is a technology that physically separates volatile and some semivolatile contaminants from contaminated media. In thermal desorption, heated air is used to volatilize contaminants at temperatures below those used for incineration. There are both in situ and ex situ applications of the technology. Ex situ treatments typically are used to remediate soil, sediments, sludges, and filter cakes. In situ applications of the technology use injected steam, thermal blankets, or heat supplied by electrodes to volatilize contaminants, which are then removed using extraction wells.

To accomplish the thermal desorption, contaminated media are heated, generally between 300 and 1000°F, thus driving off the water, volatile contaminants, and some semivolatile contaminants from the contaminated media and into the off-gas stream. The removed contaminants are then treated by thermal oxidation in an afterburner, condensed in a single- or multiple-stage condenser, or captured by carbon adsorption beds.

Thermal desorption technology is commercially available from numerous vendors. While ex situ thermal desorption technologies are the most common, several in situ techniques have been field tested and are commercially available.

Chemical contaminants for which full-scale treatment data exist include primarily volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs). These SVOCs include polychlorinated biphenyls (PCBs), pentachlorophenol (PCP), pesticides, and herbicides. Extremely volatile metals, such as mercury and lead, can be removed by higher temperature thermal desorption systems. The technology has been applied to refinery wastes, coal tar wastes, wood-treating wastes, creosote-contaminated soils, hydrocarbon-contaminated soils, mixed (radioactive and hazardous) wastes, synthetic rubber processing wastes, and paint wastes.

Inorganic contaminants or metals that are not particularly volatile will not be effectively removed by thermal desorption. If chlorine or another chlorinated compound is present, some volatilization of inorganic constituents in the waste may also occur.

Caution should be taken regarding the disposition of the material treated by thermal desorption because the treatment process may alter the physical properties of the material. For example, the matrix material could be susceptible to such destabilizing forces as liquefication, where pore pressures are able to weaken the material on sloped areas or places where materials must support a load (i.e., roads for vehicles, subsurfaces of structures, etc.).

Technology Cost
Several vendors have experience in the operation of ex situ thermal desorption systems and have documented processing costs per ton of soil or waste material treated. The overall range varies from approximately $100 to $400 (1993 dollars) per ton of material treated. Costs are also highly variable due to the following factors:

- Quantity of waste to be processed
- Terms of the remediation contract
- Moisture content

TABLE 1 Cost Information for Various Thermal Desorption Systems[a]

Site Name	System	Contaminant	Total Cost ($)	Unit Cost
Port Moller Radio Relay Station, Port Mollar, AK	ESTD	Gasoline, diesel, VOCs, TPH, BTEX	3,325,000[b]	$350/yd^3
Naval Air Station Cecil Field, Site 17, OU 2, Jacksonville, FL	ESTD	TPH, VOCs, solvents, BTEX	1,946,122	$165/ton
Re-Solve, Inc., Superfund Site, North Dartmouth, MA	ESTD	PCBs, VOCs	6,800,000	$155/ton
TH Agriculture & Nutrition Company Superfund Site, Albany, GA	ESTD	Pesticides	1,100,000	$200/ton
McKin Company Superfund Site, Gray, ME	ESTD	VOCs, PAHs, solvents, TPH	2,900,000	$250/ton
Wide Beach Development Superfund Site, Brand, NY	ESTD	PCBs	11,600,000	$280/ton
Solvent Refined Coal Pilot Plant, Ft. Lewis, WA	ESTD	PAHs	7,100,000	$68/ton
FCX Washington Superfund Site, Washington, NC	ESTD	Pesticides	1,844,600	$125/yd^3
Waldick Aerospace Devices Site, Walk Township, NJ	ESTD	BTEX, VOCs, TPH	2,017,361[c]	$585/yd^3
Rainbow Disposal Site, Huntington Beach, CA	ISTD	TPH, BTEX	4,401,120	$46/yd^3,[d]
Missouri Electric Works, Cape Girardeau, MO	ISTD	VOCs, PCBs	Not available	$120–200/yd^3
Lawrence Livermore National Laboratory, Livermore, CA	ISTD	Gasoline	10,400,000	$104/yd^3

Source: Adapted from D19487A, D18515T, D141140, D131340, D20082Y, D20081X, D19666B, D19667C, D194858, D10949J, D168698, D216002.

[a] ESTD, ex situ thermal desorption; VOCs, volatile organic compounds; TPH, total petroleum hydrocarbons; BTEX, benzene, toluene, ethylbenzene, xylene; PCBs, polychlorinated biphenyls; PAHs, polycyclic aromatic hydrocarbons; ISTD, in situ thermal desorption.

[b] Costs greater than normal due to the remoteness of the site.

[c] Costs at the site elevated because soil was contaminated with heavy metals and treated soil was disposed of as hazardous waste.

[d] A cost estimate was prepared based on a pilot-scale demonstration.

- Organic constituent in the contaminated medium
- Cleanup standards to be achieved (D131340, p. 3)

Similarly, cost estimates should include such items as preparation of work plans, permitting, excavation, processing, quality assurance/quality control verification of treatment performance, and reporting of data (D15673U, p. 7). For more specific cost estimates for ex situ thermal desorption techniques, refer to the individual technologies in the RIMS 2000 library/database.

For in situ steam-enhanced extraction, cost estimates range from about \$50 to \$300/yd^3 depending on site characteristics, particularly the depth of contamination and soil permeability. The more wells required per unit area (a function of contaminant depth), the higher the cost of remediation (D12529B). For more specific cost estimates of in situ thermal desorption techniques, refer to the individual technologies in the RIMS 2000 library/database.

Cost information for various thermal desorption applications is summarized in Table 1.

Information Sources

D15673U, U.S. EPA, 1994
D131340, U.S. EPA, 1995
D10949J, U.S. EPA, 1995
D168698, U.S. DOE, 1995
D19025K, Sullivan, 1998
D19487A, U.S. Army Corps of Engineers, 1998
D18515T, U.S. EPA, 1998
D141140, U.S. EPA, 1995
D131340, U.S. EPA, 1995
D20082Y, U.S. EPA, 1998
D20081X, U.S. EPA, 1998
D19666B, U.S. EPA, 1998
D19667C, U.S. EPA, 1998
D194858, U.S. EPA, 1998
D10949J, U.S. EPA, 1995
D168698, U.S. DOE, 1995
D12529B, U.S. EPA, May 1991
D216002, U.S. EPA, 1998

T0795

Thermatrix, Inc.

Flameless Thermal Oxidation

Abstract
Thermatrix, Inc. (TI), has developed a flameless thermal oxidation (FTO) technology to treat volatile organic compounds (VOCs) in off gases and wastewater generated in processes such as soil vapor extraction. The TI system is unique in that there are no burners, valves, or moving parts in the reactor, and the oxidation occurs in a packed-bed reaction zone consisting of chemically inert ceramic materials. FTO technology is commercially available and is currently installed at sites in 16 states. The technology is also in use in France, the United Kingdom, and Ireland.

TI states that the advantages of FTO technology include the lack of an open flame, the high destruction and removal efficiencies that can be achieved, low nitrogen emissions, and the range of process flow rates that are acceptable for treatment.

Off gases with particulate loads should be filtered before FTO processing. Waste streams with chlorine or sulfur produce acid vapors during FTO treatment that may require scrubbing prior to release. FTO technology is not appropriate for treatment of off gases with organometallic components because solid oxidation products are formed.

Technology Cost

Operational costs for Thermatrix FTO are not concentration dependent. In addition, large increases in throughput are accompanied by relatively minor increases in capital cost at moderate to high flow rates and concentrations (D12104Q, p. 37). Costs associated with the Thermatrix FTO system will vary according to site requirements and flow rates (D125122, p. 10).

In a 1996 report compiled by Los Alamos National Laboratory, cost estimates were developed for seven innovative off-gas treatment technologies as well as for three off-gas technologies currently used to remove VOCs from contaminated soil and groundwater. Estimates for FTO are summarized in Table 1 (D12104Q).

TABLE 1 Summary of Economic Analysis of Flameless Thermal Oxidation, Los Alamos National Laboratories

Cost Category	Case 1: 100 scfm[a] flow rate, inlet concentration 50 ppm[b]	Case 2: 100 scfm flow rate, inlet concentration 1000 ppm	Case 3: 500 scfm flow rate, inlet concentration 1000 ppm
Bare equipment cost (BEC),[c] $	160,000	160,000	250,000
Total equipment cost (TEC),[d] $	172,800	172,800	270,000
Total capital cost (TCC),[e] $	257,097	257,097	382,485
Total capital required (TCR),[f] $	475,629	475,629	707,597
Labor, $	10,016	10,016	10,016
Maintenance, $	15,000	15,000	15,000
Annual energy cost, $	40,925	40,925	11,588
Annual capital	$18,560	$18,560	$29,000
Unit cost ($/lb), 10 years operation[g]	109	5	1
Annual recovery of VOCs, lb/yr[h]	1,092	21,840	109,200

Source: Adapted from D12104Q.

[a] scfm = standard cubic feet per minute.

[b] The inlet stream is assumed to be 70% perchloroethylene and 30% trichloroethylene for this cost estimate (ppm = parts per million).

[c] The BEC is considered to be the cost of the base technology process equipment plus any auxiliary equipment.

[d] The TCE includes the BEC plus instrumentation, sales tax, and freight.

[e] The TCC includes the TEC plus indirect costs, site preparation, and building.

[f] The TCR is a summary of the construction capital cost plus factors for project management, engineering, design, and inspection plus construction management, management reserve, and contingency.

[g] lb/yr = pounds per year.

[h] The 10-year unit cost is the cost per pound of VOCs remediated over the 10-year life cycle of the equipment.

In a 1995 treatability study conducted for the U.S. Department of Energy (DOE) Savannah River facility, a cost estimate was prepared for an FTO system with a flow rate of 400 standard cubic feet per minute (scfm) using natural gas to maintain process temperatures. Costs were estimated at $0.72/lb. For the purposes of this estimate, the inlet concentration was assumed to be 400 ppm of trichloroethylene (TCE), perchloroethylene (PCE), and 1,1,1-trichloroethane (TCA). Capital costs were estimated at $160,000. Capital costs were amortized over 10 years, not over the time required to remediate the site. This cost estimate found FTO to be more cost effective than thermal catalytic technologies due to lower operating and maintenance costs (D125122, p. 10).

In a 1996 treatability study for McClellan Air Force Base, costs of FTO processing were estimated at $0.68 per 1000 standard cubic feet of vapor treated. The gas stream contained 567 ppm TCE and lesser concentrations of other VOCs. The flow rate was 500 scfm (D125097, pp. 8, 11). Costs associated with a competing technology, catalytic oxidation, were estimated at $0.99 per 1000 scfm over a 5-year period. The main difference between the estimates was the lower maintenance and labor cost associated with the FTO system (D125097, p. 11).

The U.S. Air Force purchased a Thermatrix GS Series FTO treatment system for $235,265 for remediation at Plattsburgh Air Force Base, a former fire training site, in New York. The total capital cost, estimated over a 3-year period, was less than the commercial cost of $275,265 (D18550W, pp. 411–413).

The capital costs for an ES-300H unit tested by the U.S. Navy at Naval Air Station North Island were estimated to be $50,000. For the test, electric power costs were calculated to be $6.78 per day, which would equal $2475 per year. This estimate includes the cost of operating the unit as well as the cost of running an air compressor required for treatment. Based on demonstration results, monitoring costs for the unit would add an additional $6300 per year (180 worker-hours per year at $35 per worker-hour) (D21558H, pp. 4–1, 4.2).

Information Sources

D12104Q, Cummings and Booth, 1996

D125097, McClellan Air Force Base, 1996

D125122, U.S. DOE, 1995

D18550W, Guest et al., undated

D21558H, U.S. Navy, 1996

T0796

Thermatrix, Inc.

PADRE Vapor Treatment Process

Abstract

The Thermatrix, Inc., PADRE process is a commercial, off-gas treatment technology that purifies airstreams contaminated with volatile organic compounds (VOCs). The PADRE vapor treatment process traps VOCs using filter beds that contain a proprietary resin. This regenerative adsorption method involves an on-line treatment bed for influent air, while another bed undergoes a desorption cycle. PADRE often works in conjunction with soil vapor extraction or air stripping systems. The PADRE process can be applied at site remediation projects, industrial wastewater facilities, and industrial air processing sites.

Adsorbent beds used in the PADRE process have been recycled on a test stand more than 2000 times with no measurable loss of adsorption capacity. Also, the PADRE resin has a relatively high tolerance for water vapor, allowing efficient treatment of airstreams with a relative humidity of greater than 90%. These two advantages make the PADRE process a cost-effective on-site treatment technology when compared to traditional activated carbon systems.

The PADRE system is limited to VOCs. The process is not appropriate for airstreams containing vinyl chloride since it is difficult to maintain vinyl chloride in a condensed form.

Technology Cost

Estimated unit prices for treatment of VOCs using the PADRE vapor treatment process range between $1.00 and $3.00/lb. The initial contaminant concentration, volume of gas stream to be treated, and target cleanup levels have significant impact on unit price. These price estimates do not necessarily include all indirect costs associated with treatment, such as excavation, permits, and treatment of residuals (D13375F, p. 15).

In 1995, the vendor estimated the costs associated with a PADRE system. The purchase price of a system was $132,500, and the monthly rental rate was $7000. Based on a price of $0.06/kWh, the monthly electrical costs were estimated at $254. Assuming a price of $80 per liquid nitrogen dewar, the costs for nitrogen gas would be $487 per month. Additional maintenance on the system would cost approximately $500 per month (D212351, pp. 2–6).

During a 110-day field demonstration at the U.S. Department of Defense's (DOD's) Vandenberg Air Force Base in Lompoc, California, a PADRE system was used to treat off gas from a soil vapor extraction system. The off gas was contaminated with total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, and xylene (BTEX) from a leaking underground storage tank. The demonstration costs were $36,634. This figure included $2500 for set-up, $25,667 for rental, $4,500 for operation labor, $1212 for power, $1760 for nitrogen, and $1000 for mobilization and demobilization. The unit treatment cost was approximately $23/kg of hydrocarbons removed (D21036W, pp. 46, 47).

Information Sources

D13375F, VISITT 4.0, 1995

D21036W, Federal Remediation Technologies Roundtable, 2000

D212351, U.S. DOD, 1995

T0797

Thermo Design Engineering, Ltd.

Clean Soil Process

Abstract

Thermo Design Engineering, Ltd.'s, clean soil process (CSP) is a separation and volume reduction technology that uses both physical and chemical processes to remediate contaminated soil. The technology uses coal (as a cleaning agent) to remove tarry/oily contaminants from soil. The CSP technology relies on a solid-to-solid abrasive mass transfer mechanism, which is produced by the high affinity of hydrocarbon contaminants to coal and the low affinity of these contaminants to mineral matter. Although coal is used primarily as the contaminant adsorbent, a variety of organic carbonaceous solids (coke and char) can be used.

The CSP technology can treat a wide variety of soils contaminated with tars, fuel oils, halogenated solvents, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), cyanides, phenols, and heavy metals. The CSP technology's use of coal as a cleaning medium makes it particularly useful for treating soils contaminated by manufactured gas plants.

The CSP technology performs well with soils containing much greater than 1% tar, and the technology is less expensive than incineration.

Technology Cost

According to the vendor, processing costs for the technology can be as low as $14 to $16 per ton for contaminants such as No. 6 fuel oil and up to $25 per ton for a plant that treats 240 to

250 tons of soil per day (personal communication, Leszek Ignasiak, Alberta Research Council, October 1996).

Information Source

Vendor information (telephone contact)

T0798

Thermo Nuclean

Segmented Gate System

Abstract

Thermo Nuclean developed the segmented gate system (SGS) to segregate radioactive material from contaminated soil. The SGS is a combined system of conveyors, radiation detectors, software algorithms, and computer controls. The SGS diverts contaminated soil onto a conveyor belt that deposits the soil in a container for disposal or further processing. The developer claims that the system removes minimal amounts of clean soil with the radioactive particles, reducing the amount of material requiring disposal. The SGS is commercially available.

The SGS locates, analyzes, and removes gamma-ray-emitting radionuclides from soil, sand, dry sludge, or any host matrix that can be transported by conveyor belts.

According to the developer, automation is the major advantage of the SGS, affording a higher degree of accuracy in comparison to manual methods. Another advantage of the SGS is that it can be coupled as a pretreatment with secondary downstream decontamination methods to affect further volume reduction.

Technology Cost

In 1999, the SGS was used at the U.S. Department of Energy's (DOE's) Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico, to sort 2526 yd^3 of soil and debris contaminated with up to 431.46 picocuries per gram (pCi/g) of uranium from the production of nuclear weapons. The actual cost for the operation was $275,745. This figure included $6600 for predeployment activities, $46,000 for mobilization, $185,445 for processing, $35,000 for demobilization, and $2700 for the final report. LANL incurred $543,400 in additional costs for staff, the prime contractor, recharges, and soil disposal. The overall unit cost was $109/$yd^3$ of soil processed (D21040S, p. 70; D21230W, pp. 13, 14).

Approximately 294 yd^3 of soil contaminated with uranium from a firing range at the DOE's Pantex Plant in Armarillo, Texas, was sorted using the SGS technology. The 1998 remediation had an actual cost of $203,887. This included $18,768 for regulatory and compliance issues, $103,015 for mobilization, $32,594 for soil processing, and $49,510 for demobilization. Additional costs for site preparation, oversight labor, health physics support, sample analysis, and waste disposal were absorbed by the DOE. The average unit cost was approximately $111/$yd^3$ of soil processed (D21040S, p. 72; D21232Y, pp. 15, 16).

An SGS was used to segregate uranium-contaminated soil at the ER Site 16 Concrete Dump Site at the DOE's Sandia National Laboratories in Albuquerque, New Mexico. The actual cost of the full-scale remediation was $164,109, including $59,326 for mobilization, $57,770 for operations, and $47,013 for demobilization. Based on the 661.8 yd^3 of soil processed, the unit cost of the operation was $236/$yd^3$. Site preparation, crane operation, oversight labor, health physics support, water supply, sample analysis, and waste disposal were not included in the actual or unit costs (D21040S, p. 74; D21233Z, pp. 12, 13).

At the DOE's Sandia National Laboratory ER Site 228A in Albuquerque, New Mexico, an SGS was used to sort 1352 yd^3 of soil contaminated with uranium from burial pits. The unit cost of $154/$yd^3$ was based on the operation's actual costs of $220,040. These costs included $29,000 for excavation and prescreening activities, \$41,300 for mobilization, \$117,000 for operations, and \$32,340 for demobilization. Project costs did not include oversight labor, health physics support, water supply, fuel services, generator support, sample analysis, or waste disposal (D21040S, p. 76).

During a Nevada field demonstration, approximately 333 yd^3 of soil and debris contaminated with up to 1100 pCi/g of plutonium was processed at the U.S. Department of Defense's (DOD's) and DOE's Tonapah Test Range. The actual cost of the demonstration was \$138,126. This figure included \$8203 for regulatory and compliance issues, \$29,614 for mobilization, \$78,545 for physical treatment, and \$21,764 for demobilization (D21040S, p. 78; D21231X, p. 14).

According to the DOE, a high-capacity SGS system that operates at 30 yd/hr would have an average treatment cost of \$50 to \$75/yd^3 (D20116R, p. 5). Another report from the DOE estimates that the system's operational costs range from \$55 to \$85/yd^3 (D21574H, p. 2).

Information Sources

D20116R, U.S. DOE, undated

D21040S, Federal Remediation Technologies Roundtable, 2000

D21230W, U.S. DOE, 1999

D21231X, U.S. DOE, 1999

D21232Y, U.S. DOE, 1999

D21233Z, U.S. DOE, 1999

D21574H, U.S. DOE, 1998

T0799

ThermoChem/Manufacturing and Technology Conversion International, Inc. (MTCI)

PulseEnhanced Steam Reformer

Abstract

Manufacturing and Technology Conversion International, Inc.'s (MTCI), PulseEnhanced™ steam reforming technology uses an indirectly heated, fluid-bed reactor to react low-level mixed wastes, such as biomass, coal, municipal solid waste (MSW), and wastewater sludges, with steam to give a product gas that can be used as fuel or feedstock for industrial processes. According to the vendor, the technology is clean due to the utilization of reduction reactions as opposed to oxidizing reactions and thus avoids the creation of combustion by-product contaminants such as oxides of sulfur.

The vendor claims the following benefits for the technology:

- Avoidance of ash melting
- No slagging/fouling and related hazards
- Modularity
- High thermal efficiency with low emissions
- Cost-effective, low power consumption
- Produces a medium British thermal unit (Btu), reformate gas
- Stable operation
- Volume reduction of 20–200 to 1
- Destruction of hazardous organic materials, without the production of dioxin
- Final waste streams readily coupled to processes such as vitrification or encapsulation for disposal of low-level mixed waste

According to the vendor, a limitation of this technology is the need to screen or crush material to less than one inch in size before processing.

Technology Cost

In an engineering study, ThermoChem developed several cases for a refuse-derived fuel (RDF) gasifier and applied them to five options for energy recovery. The gasifier cases were for 227 and 595 megagrams per day (Mg/d) [250 and 655 tons per day (t/d)] RDF facilities; 300- and 726-Mg/d (330- and 800-t/d) municipal solid waste equivalents were based on ThermoChem's waste. The major components of the steam reformer consisted of:

- Fluidized-bed reformer, including pulsed heaters to supply the heat required to dry the RDF
- Waste-heat recovery steam generator in the product gas stream to generate steam for fluidization
- Feedstock dryer using heat recovered from the product gas
- Quench system to cool the gas and remove entrained particulates
- Char handling system
- Steam superheater and an air heater installed on the pulse combustor flue gas (D13938S, p. 9–2)

The dryer and heater were not used in all configurations. In cases 1A, 1B, 2A, and 2B, the steam reformer operated at 816°C (1500°F) and processed 227 Mg/d (250t/d) wet RDF. Cases 3A and 3B processed waste at 595 Mg/d (655 t/d) at the same temperature. A feed dryer or an air heater were not included in the cases denoted A, thereby exhibiting a lower cold-gas efficiency. The feed dryer and air heater were included on the B cases, increasing the cold-gas efficiency. The overall thermal efficiency was over 78% for the A cases and about 87% for the B cases (D13938S, p. 9–2). The operating and maintenance costs are estimated to be \$21.25/ Mg (\$19.32/t) RDF for cases 1A and 1B, \$10.95/ Mg (\$9.95/t) for cases 2A and 2B, and \$10.01/ Mg (\$9.10/t) for cases 3A and 3B (D13938S, p. 9–2).

ThermoChem conducted a study at New Bern, North Carolina, using a five-heater fluid-bed steam reformer that can process 109 Mg/d (120 t/d) black liquor. The throughput was 479 Mg/d (528 t/d) dry RDF [595 Mg/d (655 t/d) wet RDF or 849 Mg/d (935 t/d) MSW] for a combined-cycle gas turbine. A gasifier temperature of 816°C (1500°F) with a duty of 264,000 MJ/hr (250 $\times 10^6$ Btu/hr) was assumed. The capital costs for the project are given in Table 1 and operating costs are given in Table 2 (D13938S, p. 9–2).

TABLE 1 Capital Cost: ThermoChem Steam Reforming Processing System For Municipal Solid Waste (MSW)[a]

Facility Capital Investment	Cost
Fuel preparation	\$37,000,000
Process core cost	
Process/heat recovery/APC train	\$15,141,000
Equipment (installed) CEM system	\$1,000,000
Engineering and contingency (30% of process core cost)	\$4,842,000
Electrical generation (steam turbine)	\$33,750,000
Total	\$91,733,000
Cost for metric ton per day MSW	\$108,000
Cost for ton per day MSW	\$98,100

Source: D13938S, Niessen et al., 1996.

[a]System consists of 849 Mg/d (935 t/d) and 595 Mg/d (655 t/d) RDF.

Bubbling fluid-bed furnace indirectly heated by using steam as the fluidizing medium PulseEnhanced heater. Air pollution control (APC): wet scrubber.

TABLE 2 Operating Costs for ThermoChem PulseEnhanced Steam Reforming

Cost Element	Unit Cost	Annual Cost (thousands of $)
Labor	$25.00–$45.00 per hour	1,584
Maintenance—Supplies		52
Maintenance	3% of capital	629
Insurance	1% of capital	210
Compliance testing		300
Residue landfill	$40/ton	4403
Total cost for process core		7079
Contingency	10% process core	708
Debt service	10.19% of capital	9348
RDF operations	$8.50/ton	2465
Electric gen. operations		1750
Total gross cost		21,350
Net annual cost		11,722
Unit cost ($/ton)		40.42
Unit cost ($/metric ton)		44.50

Source: D13938S, Niessen et al., 1996.

Information Source

D13938S, Niessen et al., 1996

T0800

ThermoEnergy Corporation

NitRem

Abstract

NitRem is an ex situ, noncatalytic, near-critical hydrothermal process used to treat wastewater contaminated with organic and nitrogen-containing compounds. The process converts nitrates, nitrites, ammonia, and organic nitrogen sources into nitrogen gas, water, and carbon dioxide. NitRem may be used alone to treat aqueous waste streams or in tandem with another technology such as wet air oxidation (WAO) or sludge-to-oil reactor systems (STORS) to treat more complex waste streams.

The patented NitRem technology was developed by the Department of Energy's (DOE's) Battelle Pacific Northwest Laboratories (BPNL) to treat nitrogen-rich wastewater from the STORS technology. The Navy Environmental Leadership Program (NELP) has conducted bench-scale testing of the NitRem system on wastewater from Naval Air Station North Island. In 1997, a NitRem demonstration was conducted at the Department of Defense (DOD) Radford Army Ammunition Plant in Radford, Virginia. NitRem is commercially available through ThermoEnergy Corporation.

This technology only treats aqueous waste streams.

Technology Cost

ThermoEnergy Corporation has combined the NitRem process with WAO technology to treat municipal wastewater. According to the vendor, the small-scale, NitRem/WAO plant is estimated to cost under $15,000,000 (D19769H, p. 1).

TABLE 1 Preliminary Budget for the STORS/NitRem Demonstration in San Bernadino, California

Item	Cost ($)
STORS/NitRem equipment	2,050,000
Engineering/design/fabrication	205,000
Construction (site preparation)	50,000
Administrative costs (project hosts)	100,000
Training/operation/safety manuals	55,000
Hauling/disposal	30,000
Power requirements	50,000
Project shakedown/installation	15,000
Decommissioning/project closure	35,000
Environmental consultant(s)	50,000
Operating costs	245,000
Labor	70,000
Travel	25,000
Final reports/documentation	20,000
Total project costs	3,000,000

Source: From D202380.

The cities of Colton and Grand Terrace in San Bernadino County, California, will conduct an 18-month demonstration of the Nitrem process and the STORS technology. The total costs of the project are estimated at $3,000,000 (D202380, p. 2). Table 1 shows the demonstration's preliminary budget.

Information Sources

D19769H, ThermoEnergy Corporation, 1999

D202380, ThermoEnergy Corporation, undated

T0801

Thermoplastic Stabilization/Solidification — General

Abstract

Thermoplastic stabilization/solidification (S/S) is a technology for the ex situ treatment of radioactive, mixed, and hazardous wastes. It is a process that uses thermoplastic polymers to physically immobilize the hazardous constituents of contaminated soils, sludges, sediments, or even liquid wastes. The idea is to prevent the migration of contaminants into the environment by forming a low-permeability solid mass. The goal of this technology is to immobilize contaminants within the existing medium, rather than to try and remove them via chemical and/or physical treatments.

Thermoplastics are polymeric materials that soften when heated and, upon cooling, will harden again. Ideally, the thermoplastics used in this type of technology are pourable when hot, so that they can be mixed with waste and form a barrier impermeable to water when resolidified.

The primary focus of most thermoplastic S/S research has been for the solidification and stabilization of radioactive and mixed wastes prior to long-term storage. Thermoplastic S/S can also be used for electroplating sludges, painting and refinery sludges containing metals and organics, dry incinerator ash, and fabric filter dust.

Technology Cost

Thermoplastic S/S is often more expensive than other S/S methods because the waste often requires more pretreatment and processing and can be more difficult because of the higher temperatures and specialized equipment involved (D150141, p. 7.89).

The final costs are highly dependent upon site-specific conditions. Contributing factors to the final cost of treatment include the waste characteristics, such as physical form and chemical makeup; the amount of pretreatment required; transportation of raw materials to the site and treated materials from the site; the type of S/S process used; and other random factors such as health and safety requirements and regulatory factors (D150141, p. 7.100). Because these factors cause wide variations in the cost of treatment, accurate generalizations cannot be made about the cost.

Specific cost information can be found in the individual technology summaries.

Information Source

D150141, U.S. EPA, 1989

T0802

Remediation Technologies, Inc. (RETEC)

Microbial Fence

Abstract

Microbial Fence™ is a commercially available, in situ technology for the treatment of groundwater contaminated with petroleum hydrocarbons and other biodegradable contaminants. The technology introduces oxygen to the subsurface to stimulate natural aerobic biodegradation, forming a microbial barrier to treat and control the migration of dissolved organic contaminants.

According to the vendor, Microbial Fence has been used to treat groundwater contaminated with polycyclic aromatic hydrocarbons (PAHs); benzene, toluene, ethylbenzene, and xylenes (BTEX); and volatile organic hydrocarbons (VOCs) at petroleum, chemical, and wood treating facilities and manufactured gas plants. Microbial Fence was used alone or in conjunction with soil venting/bioventing, aquifer aeration, pump-and-treat methods, and/or recovery of non-aqueous-phase liquids (NAPLs).

Advantages of microbial barriers over conventional pump-and-treat systems are that barriers can eliminate the need for additional treatment, and they do not disrupt the natural flow of groundwater. Furthermore, if contaminants can be volatilized or biodegraded throughout the impacted portion of an aquifer, there is no need for surface treatment systems, discharges, or permits.

The vendor claims Microbial Fence has the following advantages:

- Relatively simple installation and lower maintenance than pump-and-treat systems
- Less costly than conventional containment options
- No surface discharge requiring treatment or permits
- Effective as both a containment and a treatment option.

All information is from the vendor and has not been independently verified.

The equipment used for oxygen-supplied microbial barriers can have high capital costs and require ongoing power and maintenance. Also, designing and installing some microbial barriers can be difficult and costly.

Technology Cost

The price per pound of treated waste is estimated to be $8.00 to $15.00. The price varies based on the quantity of the waste, the characteristics of the soil, the initial contaminant concentration, and the depth to groundwater (D103731, p. 23).

The total cost of a field demonstration at a former wood preserving facility in Minnesota was $125,000 (D103731, p. 10).

The installed cost of a 2100-ft Microbial Fence at a petroleum refinery in the western United States was approximately $400,000 (D18304K, p. 4).

Information Sources

D103731, VISITT 4.0, 1995
D18304K, Brubaker, 1998

T0803

Remediation Technologies, Inc. (RETEC)

Prepared-Bed Bioremediation

Abstract

The prepared-bed bioremediation technology is an ex situ, transportable process that uses naturally occurring bacteria to convert hazardous organic contaminants into carbon dioxide and water.

The commercially available bioremediation process occurs in an engineered land treatment cell or prepared bed. Contaminated soils and sludges are excavated and transported to the treatment cell (or bed). Nutrients, water, and oxygen (introduced by tilling the soil) are added to the bed to accelerate the treatment process. After bioremediation is complete, the treatment cell is capped and the site is considered suitable for use.

The technology can be used to treat hydrocarbon-contaminated soils and sludges resulting from petroleum refining and marketing, wood treating, and petrochemical industry activities. The technology can also treat sediments.

The technology developer claims that one advantage of the technology is its ability to destroy contaminants, thereby reducing future liability associated with the contaminants.

The high selectivity of bioremediation prevents the following organic contaminants from being treated by the prepared-bed remediation technology: highly halogenated compounds such as carbon tetrachloride and highly chlorinated polychlorinated biphenyls (PCBs). According to the technology developer, the following additional limitations apply:

- Requires sufficient space to implement.
- Quantity of material that can be treated is limited.
- Requires 1 to 2 years to remediate a site.

Technology Cost

According to the developer, the cost for using the prepared-bed bioremediation technology ranges from $20 to $125/yd^3 of material treated. The cost is 5 to 20% less than the cost of incineration (D10371Z, pp. 2, 39).

Among the factors that affect the cost for using the technology are:

- Soil matrix
- Target contaminant concentration
- Initial contaminant concentration
- Moisture content of the soil
- Waste quantity (D10371Z, p. 39)

Information Source

D10371Z, VISITT 4.0

T0804

Remediation Technologies, Inc. (RETEC)

Slurry-Phase Bioremediation

Abstract
The Remediation Technologies, Inc. (RETEC), slurry-phase bioremediation (liquid-slurry treatment) is an ex situ technology that uses naturally occurring bacteria to breakdown hazardous organic chemicals. The degradation process occurs in an engineered reactor, such as a lined lagoon, tank, or other similar vessel.

According to the vendor, the technology treats halogenated and nonhalogenated organic compounds, including some pesticides and herbicides.

According to the technology developer, the technology is suitable for soil, nonmunicipal sludge, and natural sediment and is also applicable to a wide variety of hydrocarbon-contaminated soils and sludges from the petroleum refining/marketing, wood treating, and petrochemical industries.

Technology Cost
According to the vendor, Remediation Technologies, Inc. (RETEC), slurry-phase bioremediation technology costs $30 to $600 per ton of waste treated. Among the factors that affect the cost are:

- Initial contaminant concentration
- Target contaminant concentration
- Soil matrix
- Waste quantity (D103720, p. 39)

Information Source

D103720, VISITT 4.0

T0805

Remediation Technologies, Inc. (RETEC)

Thermatek Thermal Desorption

Abstract
The Remediation Technologies, Inc. (RETEC), Thermatek thermal desorption system is an ex situ high-temperature treatment technology that treats soils, sediments, and sludges contaminated with volatile organic compounds (VOCs) and polychlorinated biphenyls (PCBs). The process uses a conventional Holo-Flite™ thermal desorption unit with RETEC's proprietary modifications, using an indirect heating source.

According to the vendor, the Thermatek thermal desorption system is no longer being used for soil remediation. The Thermatek thermal desorption system is commercially available for use in recovering oil product from wastewater treatment sludges in petroleum refineries.

According to the vendor, this technology has the following benefits:

- Is effective for the treatment and mass reduction of a wide range of organic wastes.
- Meets and exceeds U.S. Environmental Protection Agency's (EPA's) Best Demonstrated Available Technology (BDAT) standards for refinery wastes.
- Treated solids are technically delistable.
- Recovery and recycle of organic components.
- Reliability and simplicity of operation.
- Low capital and operating costs.
- Exempt from Resource Conservation and Recovery Act (RCRA) permitting due to recovery and recycling of the organic components of the waste.
- Safety and environmental acceptability.

This technology is not cost competitive with lower-temperature thermal desorption units when the organics have low boiling points (less than 400°F). In addition, if the material handling system is designed for dewatered sludges, it will not efficiently accommodate wet sludges.

Technology Cost

According to vendor-supplied information in VISITT 4.0, the estimated price range for this technology is $100 to $600 per ton of waste treated (1995 dollars). These estimates do not always include all indirect costs associated with treatment such as excavation, permits, and treatment of residuals.

Factors that have a significant effect on unit price include the following:

- Quantity of waste
- Target contaminant concentration
- Initial contaminant concentration
- Moisture content of soil
- Site preparation
- Characteristics of soil
- Amount of debris with waste (D10370Y, p. 37)

Information Sources

D10370Y, VISITT Version 4.0, 1995
D12902C, Remediation Technologies, Inc., 1991

T0806

Thermotech Systems Corporation

Soil Remediation Unit

Abstract

Thermotech Systems Corporation (Thermotech) has patented a thermal desorption, two-stage tandem soil remediation unit (TDU) that treats and desorbs light and heavy hydrocarbons from contaminated soils, clays, and drilling muds. Thermotech's TDU does not incinerate soil, but rather cleans and recycles it. The technology has been commercially available since 1991.

The Thermotech two-stage Tandem® desorber can be used to desorb and then thermally oxidize petroleum contaminants from soils, including clays and soils with high grain loadings. The technology treats light to heavy hydrocarbons (including No. 6 bunker and crude oil).

The vendor lists the following advantageous features for the Thermotech system:

- Countercurrent desorption
- Low desorber gas velocities
- Efficient heavy organics processing
- Superheated desorber gases
- DPC-100 distributed plant control graphics station
- Both light and heavy hydrocarbon remediation

The Thermotech TDU has the following limitations:

- Cannot treat hydrocarbon contamination levels >3% (by weight).
- Cannot treat toxic metals.

Technology Cost
The following estimated costs were given for using the Thermotech TDU to treat the listed compounds (personal communication: Larry Johnson, Dustcoating, February 1997):

- Cost for using Thermotech Model 232 (same as Model 625) for treating total petroleum hydrocarbons (TPHs) was approximately $40 per ton of material treated.
- Cost for using Thermotech Model 232 (same as Model 625) for treating pesticides and herbicides was $150 per ton of material treated.
- Cost for using Thermotech Model TD-90 to treat polynuclear aromatic hydrocarbons (PAHs) was $100 to $120 per ton.

Among the factors that affect the cost are soil moisture content, boiling point or vapor pressure of contaminants, debris content of the waste, and other soil characteristics (D10350U, p. 18).

Information Source

D10350U, VISITT 4.0

T0807

Thorneco, Inc.

Enzyme-Activated Cellulose Technology

Abstract
The enzyme-activated cellulose technology is an ex situ process that was designed to treat contaminated water. Cellulose, coated with a proprietary enzyme, is used to remove metals and organic compounds from an aqueous solution.

The technology's efficiency is affected by operating parameters including flow rate, cellulose dosage, enzyme coating, and pH. A treatability study conducted by the Environmental Protection Agency (EPA) determined that metals and nitrate removals were enhanced by the treated cellulose. Phenol removal, however, was not enhanced by the technology. In addition, solid residues produced from the study required incineration due to the concentration of chlorinated hydrocarbons. This technology is not commercially available.

Technology Cost
According to the vendor, the cost of implementing the enzyme-activated cellulose technology can reach as low as $0.40 per 1000 gal of contaminated water treated (D140738, p. 52).

Information Source

D140738, Roy, 1993

T0808

Toledo Engineering Company, Inc.

High-Temperature Joule-Heated Vitrification

Abstract
Toledo Engineering Company, Inc., is the developer of several high-temperature, joule-heated vitrification systems for the treatment of hazardous and radioactive wastes. In a joule-heated system, an electrical current is passed through molten wastes between electrodes, creating heat that can be used to destroy organic contaminants, and convert inorganic contaminants and metals into a molten form that can be incorporated into a glass waste product. Toledo Engineering Company systems have been designed that can treat both low-level and high-level radioactive waste as well as mixed waste (waste containing both radioactive and hazardous components). Bench-scale testing has also taken place for treatment of waste contaminated with heavy metals.

The joule-heated, high-temperature, cold-top melter system that serves as the cornerstone of the Toledo Engineering Company product line has been commercially available for glass-making operations for over 40 years. The company also offers low-temperature melters, fossil-fuel-fed melters, plasma arc melters, and cold wall melters. Toledo Engineering melter technology is currently commercially available.

Toledo Engineering claims the following advantages of high-temperature, joule-heated melters:

- Increased flexibility to develop glass formulations with higher waste loading, higher durability, and greater volume reduction
- Decreased melter size
- Reduced high-volatility metal and radionuclide emissions
- Increased flexibility in feeds and waste chemistries

Organic contaminants are currently a limitation of Toledo Engineering's processing due to its impact on the redox state of the product glass. Currently Toledo Engineering melters can treat organic material at a maximum content of 3 to 7%, but the firm is researching designs for melters to handle situations where the primary feed is organic in nature.

Technology Cost
In undated vendor literature supplied in 1997, Davis estimates that treating a hazardous waste incinerator waste stream would cost from \$131.30 to \$266.90 per ton of dry waste treated. This cost estimate is summarized in Table 1. Costs vary depending on feed rate and the degree of waste reduction achieved during treatment. The estimate was performed for two types of glass compositions, which are described in Table 2. The vendor notes that the cost of vitrification and alternate options for any waste is highly site specific and include the individual factors determining total costs to provide a basis for comparison (D14867Y, pp. 6–10).

It is assumed in estimates 1 and 3 that a single Toledo Engineering melter would be used. For estimates 2 and 4, a bank of four melters operating in tandem was used. For estimates 2 and 4, it was assumed that at any one time three of the four melters would be operational. It is noted that the use of injected air or oxygen instead of sodium nitrate would lower treatment costs (D14867Y, p. 8).

The vendor notes that the energy required for melting is the largest component of cost, and that these costs would be highly site dependent. Abatement costs for the off-gas were estimated

TABLE 1 Cost Estimate in Dollars/Ton for Toledo Engineering Company Treatment of Incinerator Ash

Dry waste/glass ratio	0.70	0.70	1.05	1.05
Tons/day glass produced	25	100	16.7	66.8
Tons/day dry waste processed	17.5	70	17.5	70
Premelting costs				
Raw materials	33.40	33.40	0	0
Pretreatment				
Capital	6.30	2.10	9.00	3.00
Utilities	5.60	4.40	7.70	6.60
Manpower	5.70	2.90	8.60	4.30
Batch house				
Capital	11.00	3.60	14.70	4.60
Utilities	1.20	0.60	1.50	0.70
Manpower	5.70	2.90	8.60	3.20
Melting costs				
Capital	13.60	12.20	20.30	13.60
Utilities	62.10	61.70	65.30	64.70
Manpower	22.90	17.10	34.20	17.10
Forming costs				
Capital	0.90	0.90	1.40	0.90
Utilities	0.30	0.20	0.40	0.30
Manpower	1.90	1.40	2.90	1.60
Rebuild accrual costs	6.90	6.90	6.90	6.90
Maintenance supply costs	4.00	4.00	4.00	4.00
Maintenance labor costs	5.70	4.30	8.60	6.40
Total cost/ton of glass produced	187.30	158.50	194.00	137.90
Total cost/ton of dry waste treated	266.90	225.90	184.70	131.30

Source: Adapted from D14867Y.

TABLE 2 Composition of Glass Types Used for Economic Analysis

Component	Optimized Glass Form with Additives	Nonadditive Glass Formulation
Bottom ash	60%	90%
Fly ash	6%	10%
Sand	25%	0%
Sodium nitrate	7%	0%
Soda ash	3%	0%
Waste/glass ratio[a]		
Dry	0.7	1.05
Wet	1.0	1.3

Source: Adapted from D14867Y.

[a]The ratio of the weight of the untreated waste to that of the glass product.

at $0 because the estimate was based on a waste stream that had already been processed by an incinerator. Forming of the wastes is accomplished by directing the molten glass stream into water, cracking the glass. A continuous screw mechanism takes the produced glass out of the water for further draining. The produced glass may have economic applications as a binder material, filler, or as a component of glasphalt. In the estimate of rebuild accrual and maintenance is the cost of replacing the inner lining of refractories in the melter and other expected maintenance (D14867Y, pp. 8–10).

Most of the cost data for vitrification technologies are estimates based on pilot-scale operations. Such data are suspect because they are based more on extrapolation than on experience. Such estimates are difficult to compare because the assumptions on which they are based may vary widely (D18248T, p. 55).

Many site-specific characteristics have an impact on vitrification technologies. One critical aspect of any thermal technology is the water content of the waste. Water dilutes feed material, requires energy to drive off, and physically limits the feed rate of waste. Feed preparation is another variable, which differs with the technology and with site-specific characteristics. Some technologies can accept complete barrels of waste at a time, while others require pretreatment and size reduction. Many estimates do not take into account site preparation and waste disposal costs. Only complete treatment life-cycle assessments can provide reliable comparison data, and such studies are, by definition, highly site and waste specific (D18248T, p. 55).

Various sources estimate vitrification costs as ranging from under $100/ton to over $1000/ton for units treating hazardous waste. These estimates are assumed to be for treatment only, not including pretreatment and disposal costs. The extreme variability of the costs may be attributable to differences in feed type and water content of the waste (D18248T, p. 55).

Information Sources

D18248T, Sigmon and Skorska, 1998

D14867Y, Davis, vendor literature, date unknown

T0809

Toronto Harbour Commissioners

Soil Recycle Treatment Train

Abstract

The Toronto Harbour Commissioners (THC) soil recycle treatment train is an ex situ volume reduction and treatment technology designed to treat inorganic and organic contaminants in soils at industrial and commercial sites. The THC treatment train consists of three soil remediation technologies: a soil washing technology, a technology that removes inorganic contamination by chelation, and a technology that uses chemical and biological treatment to reduce organic contaminants. For additional information on the soil washing process, please refer to the Bergmann USA Soil/Sediment Washing Technology, which is included in the RIMS library/database (T0480). The process train approach is most useful when sites have been contaminated as a result of multiple uses over a period of time. Typical sites where the process train might be used include refinery and petroleum storage facilities, sites with metal processing and metal recycling histories, and manufactured gas and coal/coke processing and storage sites.

The process configuration utilized depends on the target contaminants being essentially nonsoluble in water. If soluble components are present, the ability to reuse water may be affected and some treatment for the aqueous phase may be necessary.

The metals treatment process is not tolerant of free oil and grease. In order to be useful for a soil with free oil and grease, prior treatment will be required. The metals treatment process uses an acid solubilization step to make the metals available for removal. If the soil matrix contains

considerable free calcium carbonate or other carbonates, foaming problems may arise when the soil is acidified. In addition, the soluble components may cause handling or dewatering problems when the process effluent is neutralized.

The process is less suited to soils with undesirable high inorganic constituents, which result from the inherent mineralogy of the soils.

This technology is not commercially available, although the soil washing component is available from Bergmann USA.

Technology Cost

The overall cost of operation of a 6.6-ton/hr soil wash, metals removal, and bioslurry treatment train is estimated at $219 (1993 U.S. dollars) per ton. The individual process costs that make up this estimate are as follows:

- Soil washing: $80 (1993 U.S. dollars) per ton of feed soil
- Metals removal: $96 (1993 U.S. dollars) per ton of feed soil
- Bioslurry process: $43 (1993 U.S. dollars) per ton of feed soil

The costs of the treatment system were examined on both an integrated and on a unit process basis. This will allow the decision maker to estimate costs for other soil applications based on the process that would be required for treating the specific soil. The cost information was developed by the THC based on analysis of the overall THC demonstration that involved treating 1860 tons of soil (D10059U, pp. 3, 46, 47).

A cost analysis was also done for the hypothetical treatment of 22,000 tons of contaminated soil using the existing THC treatment plant. The total estimated unit cost for this operation is $147 (1993 U.S. dollars) per ton. The breakdown of costs by technology is as follows:

TABLE 1 Detailed Breakout of the Costs for Treatment of 22,000 Tons of Contaminated Soil Using Soil Recycle Treatment Train[a]

Cost Component	Soil Wash	Biological Treatment	Metals Removal	Total
Site preparation	N/A	N/A	N/A	N/A
Permitting and regulatory	N/A	N/A	N/A	N/A
Equipment	$317,300	$71,100	$246,900	$635,300
Startup	N/A	N/A	N/A	N/A
Labor	$872,300	$259,800	$656,900	$1,789,000
Chemicals	$66,800	$26,800	$100,000	$193,600
Maintenance supplies	$53,400	$13,800	$43,400	$110,600
Utilities (electric)	$233,200	$83,400	$66,800	$383,400
Effluent treatment and disposal	N/A	N/A	N/A	N/A
Residuals/waste shipping, handling, and transport cost	N/A	N/A	N/A	N/A
Analytical	$53,200	$26,800	$26,800	$106,800
Facility modification, repair, and replace	N/A	N/A	N/A	N/A
Demobilization	0	0	0	0
Total	$1,596,200	$481,700	$1,140,800	$3,218,700
Costs/ton	$72.55	$21.90	$51.85	$146.30

[a] N/A, not applicable.

- Attrition soil washer: $73 (1993 U.S. dollars) per ton of contaminated soil
- Slurry bioreactor process: $22 (1993 U.S. dollars) per ton of contaminated soil
- Metals removal process: $52 (1993 U.S. dollars) per ton of contaminated soil (D10059U, p. 20)

Table 1 presents a detailed breakout of the costs for the hypothetical treatment of 22,000 tons of contaminated soil using the soil recycle treatment train (D10059U, p. 21). The hypothetical case cost estimate is based on a fines content of 16.5%. The estimated cost per ton is sensitive to the percent of fines present. This occurs because the metals removal and/or biological treatment capacity can limit the utilization rate of the wash plant (D10059U, p. 21).

The vendor estimates that treatment costs using a 50- to 60-ton/hr fixed facility operating continuously at full capacity would be about $116 (1993 U.S. dollars) per ton of raw feed, assuming the fines require metals removal and organics reduction (D10059U, p. 3).

Information Source

D10059U, EPA, 1993

T0810

Toxic Environmental Control Systems, Inc.

Electrode-Assisted Soil Washing

Abstract

Soil washing is a water-based process for mechanically scrubbing soils ex situ to remove undesirable contaminants in one of two ways: by dissolving or suspending them in a wash solution (which is later to be treated by conventional wastewater treatment methods) or by concentrating them into a smaller volume of soil through simple particle size separation techniques. The performance of traditional soil washing technologies is strongly linked to particle size distribution and clay content in the soil. Because of this, soils with clay and silt contents from 30 to 50% or higher were considered untreatable by soil washing techniques because contaminants tend to bind, either chemically or physically, to clay and silt soil particles.

The electrode-Assisted soil washing (EASW) technology is being developed to treat these “untreatable” soils, using a newly patented process that boils soil slurries in a soil washing process using electricity. The EASW could be used as a stand-alone technology or could easily be integrated into another soil washing system as a treatment step for further cleaning of fine soil fractions. It is anticipated that this technology will be particularly useful for the latter.

According to the U.S. Environmental Protection Agency (EPA), volatile organic compounds (VOCs) are often easily removed from soils by soil washing techniques, while semivolatile organic compounds (SVOCs) may be removed to a lesser extent. Metals and pesticides often require acids or chelating agents for effective removal. The developer claims that this technology will be applicable to soils contaminated with petroleum hydrocarbons, chlorinated hydrocarbons, and heavy metals, and that it will be able to remove these contaminants from soils with a high percentage of clay and silt.

This technology is still being tested in the laboratory and is not yet commercially available. The developer is currently interested in negotiating for partnerships in the continuing development of this technology.

Technology Cost

At present, this technology has only been operated at a small scale in the laboratory. Based on experimental data, however, the cost of chemicals and electricity to run the EASW is estimated to be $15 per ton of soil (D14185F, p. 2). The developer also estimates that to add the EASW as an extra step to an existing soil washing technology would raise the cost of that technology by

10 to 20% (D14263C, p. 79). No information is available as to the potential cost of the EASW as a stand-alone technology.

Information Sources

D14185F, Parker, 1996
D14263C, Snyder et. al., 1995

T0811

TPS Technologies, Inc.

Thermal Desorption

Abstract
TPS Technologies operates several stationary site thermal desorption units exclusively for the ex situ remediation of petroleum-contaminated soil. After processing, the soil is tested by an independent laboratory and reused in commercial construction projects. According to the vendor, over 6000 projects have been completed. TPS has eight soil remediation facilities across the United States.

All information is from the vendor and has not been independently verified. The TPS thermal desorption process is limited to petroleum-contaminated soils.

Technology Cost
According to the vendor, the price range for this technology is \$35 to \$70 per ton (D10351V, p. 13).

Information Source

D10351V, VISITT 4.0, 1995

T0812

Trans Coastal Marine Services

Bioplug/Bioconduit

Abstract
Trans Coastal Marine Services (formerly Envirosystems, Inc.) and Louisiana State University (LSU) have developed several bioreactor systems to facilitate petroleum hydrocarbon mineralization and the bioremediation of organic wood preservatives utilizing an immobilized microbe bioreactor (IMBR) technology. These technologies can treat petroleum hydrocarbons, chlorinated solvents, pesticide-contaminated soils, and contaminated groundwater.

Vertically placed bioreactors, Bioplugs, can be installed with conventional drilling equipment while horizontal bioreactors, Bioconduits, use directional drilling equipment for installation. The individual bioreactors influence a radius of 5 ft wide. Existing site conditions determine the distance between each reactor, along with its location and specific depth within the soil.

The technologies are not commercially available. Bioplugs and Bioconduits have been implemented at several leaking underground storage tanks and industrial sites to remediate organic compounds.

Technology Cost
In one specific remediation project, the vendor claims that the cost of using a Bioplug to remediate 3300 tons of soil was 80% less than the cost for excavation and landfilling (D149966, p. 3).

Information Source

D149966, Portier and Barton, 1994

T0813

Trigon Group, L.L.C.

Soil Washing

Abstract
Trigon Group, L.L.C., designed and constructed an ex situ, continuous-flow soil washing system used primarily for separating oil and water from sand. According to the developer, the technology is applicable for remediating oil spills, sludge pits, and oil well cuttings.

The Trigon Group, L.L.C., soil washing technology uses the following steps:

- Screening and separation of coarse particles
- Agitating the soil in an aqueous solution of nonionic biodegradable detergent to promote emulsification of the oil
- Separating the sand from the emulsion
- Separating the oil in the emulsion from the detergent solution in a coalescing filter, and recycling the detergent solution

According to the developer, the Trigon Group, L.L.C., system is more effective when a solution of nonionic, biodegradable detergent is used.

The Trigon Group, L.L.C., soil washing system is commercially available.

Technology Cost
No available information.

T0814

Trigon Group, L.L.C.

Plasma Arc Continuous-Flow Furnace

Abstract
Trigon Group, L.L.C., has developed the plasma arc continuous-flow furnace for the ex situ treatment of hazardous wastes. The system is designed to minimize energy requirements by dehydrating waste material prior to treatment and by maximizing heat recovery after processing. No information pertaining to applications of the technology could be obtained, and the technology is not currently commercially available.

Technology Cost
No available information.

T0815

Trigon Group, L.L.C.

ARCHON In Situ Mixer

Abstract
The ARCHON® in situ mixer is an in situ stabilization process that combines excavation, additive addition, and mixing into a single processing step. This technology is commercially available and has been used in multiple full-scale applications.

The ARCHON in situ mixer unit consists of a hydraulically powered grinding/mixing head, typically attached to a long-reach backhoe or to a wide-track bulldozer for extensive wet areas. The process is designed to feed a continuous supply of chemical fixation and stabilization additives, which are added to the waste during the grinding/mixing operation.

As a fixation/stabilization technology, the contaminants are not degraded into nontoxic products but rather incorporated in a product intended to prevent their release into the environment.

Technology Cost
No available information.

T0816

TRW Systems & Information Technology Group

Microbial Enhanced Recovery

Abstract
Microbial enhanced recovery (MER) is an in situ technology for the recovery of petroleum hydrocarbons in groundwater. The technology is implemented after initial pumping has removed all but residual contaminants in zones of low permeability within an aquifer. The technology uses a nontoxic, microbially gelled polymer to occupy pores in zones of highly permeable soils. This process effectively seals the high-permeability zones and diverts subsurface water flow to low-permeability regions, thus improving the sweep efficiency of pump-and-treat methods. This technology is not yet commercially available.

Technology Cost
No available information.

T0817

T-Thermal Company

Submerged Quench Incineration

Abstract
The Sub-X submerged quench incineration (SQI) technology is an ex situ, down-fired liquid incinerator used to destroy organic contaminants including pesticides; military agent by-products; degradation products; solvents; ammonia compounds; copper, arsenic, and other metals; and inorganic salts. The SQI technology has been used to treat difficult-to-oxidize hazardous or toxic liquids or fumes, vent gases, and vent streams contaminated with chlorinated organic compounds. SQI systems are designed to allow for the recovery of particulate metals.

The SQI system was first used in the early 1970s and has since been used in over 125 installed systems around the world. This technology is currently commercially available.

According to the vendor, SQI technology offers the following advantages:

- T-Thermal Company has years of experience with incineration technology.
- SQI systems can achieve destruction and removal efficiencies (DREs) of up to 99.9999%.
- System can treat wastes containing organic contaminants, heavy metals, and some inorganic compounds.

Based on observations from the RMA cleanup project, downtime and reduced production may be experienced during initial periods of operation due to plugging of packed-bed scrubbers by precipitates from inorganic salts generated from the waste material.

Technology Cost

In 1999, the U.S. Environmental Protection Agency (EPA) reported that the actual cost of remediation of Basin F was approximately $93,000,000 including $14,800,000 in capital costs and $78,500,000 in operation and maintenance costs. The total costs for thermal treatment were reported to be $58,145,461. Approximately 10.9 million gallons of waste were treated, for a total unit cost of $9/ton, and the unit cost for thermal treatment was $5/ton (D18461W, p. 182).

Information Source

D18461W, EPA, 1998

T0818

TVIES, Inc.

Soil Washing

Abstract

TVIES has developed and patented an ex situ, transportable soil washing technology that uses the principle of countercurrent extraction in augers, hydrosizers, flotation cells, and clarifiers. The technology removes contaminants by using a combination of high-pressure water spray, chemical washing, and dissolved air flotation with appropriate acids, bases, and oxidation or reduction conditions.

The developer notes that the technology can extract hydrocarbons from mixed sludge and metals from gravels, sands, and clay. According to the developer, the technology treats the following compounds:

- hydrocarbons such as petroleum, diesel, kerosene, asphalt, polynuclear aromatic hydrocarbons (PAHs) (in creosote and coal tars), solid oils, pentachlorophenols (PCPs), polychlorinated hydrocarbons, and hydrocarbons containing a substantial fraction of polar asphaltic components [wastes designated by the Resource Conservation and Recovery Act (RCRA) as K-051 wastes]
- metals such as lead, cadmium, arsenic, mercury, copper, zinc, and radium
- radioactive materials such as uranium and naturally occurring radioactive materials (NORM)

The developer claims that the technology is applicable for remediation at refineries, wood treating sites, old town gas plants, and at sites where weathered hydrocarbons contain a substantial fraction of polar asphaltic components.

The developer notes that one advantage of the system is that the capacity of the system can be increased by using parallel augers, without increasing the area needed to set up the equipment.

Technology Cost

The TVIES, Inc., soil washing system has a cost range of $30 to $100/yd^3 for hydrocarbon remediation, and a cost range of $30 to $150/yd^3 for metals remediation. The remediation of nuclear materials can cost up to $600/yd^3 if the soil has been packed in drums, because drum handling alone is sometimes more expensive than soil remediation (D10352W, p. 2).

Among the factors that affect the cost of the TVIES soil washing technology are:

- Waste quantity
- Soil characteristics
- Labor rates
- Residual waste characteristics
- Initial contaminant concentration
- Target contaminant concentration
- Utility/fuel rates
- Amount of debris with waste
- Amount of waste handling/preprocessing required
- Moisture content of soil (D10352W, p. 31)

The technology has been used in remediatory work at the following sites:

- Tuboscope Vetco International (Deadhorse, AK)—treated 6000 yd^3 at a cost of \$200/yd^3 of material; total project cost was \$1.2 million
- Tesoro Petroleum (Kenai, AK)—remediated 189 drums at a cost of \$300 per drum
- Unocal Petroleum (Kenai, AK)—treated 600 yd^3 of soil at a cost of \$52/yd^3 of material
- Gustavus Airport (Gustavus, AK)—treated 14,000 tons of soil at a cost of \$82 per ton of material, for a total project cost of \$1,400,000 (D10352W, pp. 9–10, 14–15, 19–20, 24–25).

Information Source

D10352W, VISITT 4.0

T0819

U.S. Department of Energy National Laboratories

Enhanced Sludge Washing

Abstract
The combination of caustic leaching and water washing of sludge is known as the enhanced sludge washing (ESW) process. This technology is designed to reduce the volume of high-level radioactive waste (HLW) at U.S. Department of Energy (DOE) nuclear facilities.

Sludge washing removes various nonradioactive chemical components from the waste, which can then be treated and disposed of as low-level radioactive waste (LLW). LLW is significantly less expensive and easier to treat and discard than HLW. The ESW process was designed as a volume reduction pretreatment step for vitrification of HLW.

This technology is still in the development stage. It is not commercially available.

Technology Cost
Enhanced sludge washing is being developed to volume-reduce the 100 million gallons of HLW stored at the U.S. DOE Hanford Site near Richland, Washington. LLW is significantly less expensive to dispose of than HLW (D16174K, p. 3). The disposal costs for LLW are approximately \$15/kg of waste oxide, compared to \$450/kg for HLW (D20141S, p. 7). Therefore, it is advantageous to separate the Hanford waste into a small volume of HLW and a large volume of LLW (D16174K, p. 3).

Although no cost estimates are available for the technology itself, the developers believe that it can save several billion dollars by reducing the volume of HLW to be vitrified (D16175L,

p. 51). A cost–benefit analysis performed by Los Alamos National Laboratory estimated that the permanent disposal costs of Hanford's waste could be reduced by approximately $4.8 billion (1998 dollars) by first using ESW as a volume-reduction measure (D20575E, p. 2).

Information Sources

D16174K, Los Alamos National Laboratory, 1996

D16175L, U.S. DOE, 1996

D20141S, WPI, 1999

D20575E, U.S. DOE, 1999

T0820

U.S. Environmental Protection Agency

Reductive Anaerobic Biological In Situ Treatment (RABIT)

Abstract

Reductive biotransformation of a contaminant can occur when the contaminant serves as the terminal electron acceptor. Many contaminants that are recalcitrant to bio-oxidation will undergo reductive biotransformations. These biotransformations can lead to detoxification, mineralization, or changes in the mobility of the targeted contaminant. Hexavalent chromium and tetrachloroethene (PCE) have been investigated as candidates for reductive biotransformation. This technology may be most applicable for in situ remediation for the following scenarios: PCE contamination, low-yield aquifers, areas contaminated by both alkylbenzenes and chlorinated ethenes, and deep aquifer contamination.

Hugh Russell and Guy Sewell of the U.S. Environmental Protection Agency have investigated the application of reductive anaerobic biological in situ treatment (RABIT) to subsurface contamination in partnership with the Departments of Energy and Defense. This technology is still undergoing development and is not commercially available.

The process of reductive dechlorination requires the presence of a readily oxidizable substrate or electron donor. The addition of nitrogen and phosphorous nutrients may be required. Because oxygen is detrimental to an anaerobic process, oxygen scavengers may be required to drive the process. Tracers to monitor the biological process may also be necessary.

Technology Cost

The costs of the pilot-scale evaluation performed at the Pinellas Science, Technology and Research (STAR) Center in Largo, Florida, totaled approximately $400,000, with over half the costs associated with sampling and analyses. Most of the sampling and analyses were discretionary and were used to verify the system and concept design. This level of sampling would not be needed during a full-scale bioremediation project (D18543X, p. 19)

Information Source

D18543X, Sewell et al., undated

T0821

U.S. EPA Risk Reduction Engineering Laboratory and IT Corporation

Debris Washing System

Abstract

The U.S. Environmental Protection Agency's (EPA's) Risk Reduction Engineering Laboratory (RREL) and IT Corporation (IT) developed the debris washing system (DWS) to decontaminate on-site debris at Superfund sites. The DWS was developed to decontaminate material so that it could be considered "clean" fill for disposal (either on-site or off-site) as a nonhazardous waste.

The DWS applies an aqueous solution during a high-pressure spray cycle, followed by turbulent wash and rinse cycles. The aqueous cleaning solution is recovered and reconditioned for reuse concurrently with the debris cleaning process, reducing the quantity of process water required to clean the debris.

The DWS technology can be applied on-site to various types of debris (metallic, masonry, or other solid debris) contaminated with hazardous chemicals such as pesticides, dioxins, furan residues, polychlorinated biphenyls (PCBs), or hazardous metals. According to EPA, the technology may have broad applicability for sites that contain toxic organic and inorganic chemical residues mingled with remnants of razed structures (wood, steel, concrete blocks, bricks) as well as contaminated soil, gravel, concrete, and metallic debris (e.g., machinery and equipment, transformer casings, and miscellaneous scrap metal).

Technology Cost

During a 4-month site remediation at the Summit Scrap Yard in Akron, Ohio, a manual version of the full-scale IT Corporation DWS had a net cost ranging from \$50 to \$75 per ton for on-site debris decontamination (D107277, p. 111).

Table 1 summarizes the cost of fabricating and operating the manually operated debris cleaning system. The manual system cost \$9400 per day to decontaminate approximately 50 to 60 yd^3 of metallic debris on a daily basis. The U.S. EPA established the "clean level" for PCBs on the surface of the debris at $< 7.7\ \mu g/100\ cm^2$. The system cleaned approximately 75 to 90 tons of debris per day, depending upon the type of debris (included engine blocks, cast-iron pieces, miscellaneous metallic debris). Thus, the cost for decontaminating each ton of debris ranged from \$100 to \$125. The clean scrap was sold for \$52 per ton, and this income was used to offset the cost of cleaning the debris. Therefore, the net cost ranged from \$52 to \$73 per ton (D168552, p. 5).

An alternate means of disposal used at the site, which involved loading the debris into a truck and hauling it to a Toxic Substance Control Act (TSCA) approved landfill, had a base disposal cost of \$180 per ton of waste. The total disposal cost, including hauling fees, was \$246.30 per ton of waste (D168552, p. 6).

TABLE 1 Fully Burdened Daily Costs for On-site Cleanup at the Summit Equipment and Supply Company

Labor (including 6-man crew on site)	\$6,000
Rental fees	\$1,200
Analytical costs	\$300
Materials/per diem	\$1,150
Equipment costs	\$250
Site preparation/mobilization/demobilization (\$30,000 spread over 60 working days)	\$500
Total daily cost	\$9,400
Cost per ton at 75 tons cleaned per day	\$125
Cost per ton at 90 tons cleaned per day	\$104
Less revenue of \$52/ton for cleaned scrap	\$52
Adjusted cost per ton (75 tons/day)	\$73
Adjusted cost per ton (90 tons/day)	\$52

Source: From D168552, p. 8.

Information Sources

D107277, EPA SITE Technology Profiles, November 1994
D168552, Taylor et al., June 19–24, 1994

T0822

U.S. EPA National Risk Management Research Laboratory

Base-Catalyzed Decomposition

Abstract
The base-catalyzed decomposition (BCD) technology is a chemical dechlorination technology for the ex situ treatment of soils, sludges, and liquids contaminated with PCBs and other chlorinated compounds. In the two-step process, chlorine atoms on chlorinated molecules are removed and replaced by hydrogen atoms, using heat and commonly available chemicals in the presence of a catalyst.

This technology is applicable for the treatment of polychlorinated biphenyls (PCBs) and other halogenated contaminants, such as insecticides, herbicides, pentachlorophenol (PCP), lindane, and chlorinated dibenzodioxins and furans. The contaminant matrix can be soil, sludge, sediments, or oil. It can treat oily sludges, coal by-products, and wood-treating compounds.

Some limitations do exist. The BCD process has little effect on heavy metals. In addition, the carbon steel shell used for the unit's rotary reactor cannot be heated above 1000°F. Another limitation of the BCD process is the potential difficulty of capturing and treating residuals, such as volatilized contaminants, dust, and other condensates.

Technology Cost
The cost to operate a full-scale BCD system is estimated to be about $245 per ton. The major savings in the BCD over incineration treatments is in the lack of residuals disposal costs because no toxic substances such as dioxins and furans are created at the relatively low temperatures used in the BCD process. Since treated soil normally meets the requirements for on-site disposal, the costs of transport and off-site disposal are also eliminated (D15525J, pp. 11, 12).

During the first year of operation of a BCD facility at Guam, treatment costs were $516 per ton of processed material. The average production rate during this period was 1.3 tons per hour with an 82% online record. Costs at the site were considered high because of the high per diem, lodging, and travel costs associated with operating in Guam. If the per diem and lodging costs are removed, treatment costs drop to $418 per ton (D20226W, p. 7).

At a landfill site in Warren County, North Carolina, ETG Environmental, Inc., estimated treatment costs at $390 per ton, assuming a processing rate of 300 to 400 tons per day. In addition to treatment costs, this estimate includes the costs of excavating and backfilling soil at the site. ETG's calculation was based on the costs of reducing soil PCB levels to 20 parts per billion and maintaining PCB air emmision levels at 8×10^{-4} $\mu g/m^3$ or less. Since North Carolina's standards allowed for greater PCB soil concentrations, ETG estimated a cost of $300 per ton (D188243, pp. 82, 90).

The cost of operating a BCD system will vary from site to site, depending on factors such as soil properties and the type and volume of treated material. High clay or moisture content in soils, for example, can increase treatment costs (D20225V, p. 4).

Information Sources

D15525J, Chan and Yeh, date unknown
D188243, Hirschhorn, 1998

D20225V, Federal Remediation Technologies Roundtable, 1999 web site
D20226W, Terres et al., April 1997

T0823

U.S. Filter Corporation

PO*WW*ER Wastewater Treatment System

Abstract
The PO*WW*ER™ system was developed by Wheelabrator Clean Air Systems, Inc., a subsidiary of U.S. Filter Corporation, to reduce the volume of aqueous waste and catalytically oxidize volatile contaminants. PO*WW*ER is used to treat complex industrial and hazardous wastewaters containing mixtures of organic, inorganic, and radioactive contaminants. This proprietary, commercial technology combines evaporation with catalytic oxidation to concentrate and remove contaminants, producing a high-quality product water.

In 1992, the PO*WW*ER system was demonstrated in Louisiana under the Environmental Protection Agency's Superfund Innovative Technology Evaluation (SITE) program. This pilot plant is used primarily as a demonstration unit for companies interested in testing the system's ability to treat specific aqueous wastes. The PO*WW*ER system is no longer being marketed. A commercial waste management treatment system (employing the PO*WW*ER technology as one of the components) is currently in operation in Hong Kong, mainland China.

Although the PO*WW*ER system can treat concentrated and dilute aqueous wastes, treatment of dilute aqueous waste may require increased energy (however, brine disposal costs will be lower). Also, the PO*WW*ER system can treat a broad range of mixed aqueous waste streams, but the specific characteristics of the wastewater to be treated can affect the performance of the system. In addition, the pH and ionic strength of the waste stream, contaminant loading, nature of the contaminants, foaming, and catalytic poisons can all affect system performance.

A key advantage of the PO*WW*ER system is its ability to treat water contaminated by salts and metals. Also, PO*WW*ER can reduce high volumes of aqueous waste while producing a high-quality water effluent that can be used as boiler or cooling tower makeup water or discharged to surface water.

Technology Cost
PO*WW*ER system costs are estimates compiled by the vendor and are partly based on data from the Lake Charles SITE demonstration in Louisiana (Case Study 1, see D10060N, pp. 27–28). Estimates are affected by site-specific factors including physical site conditions, geographical site location, treatment goals, leachate characteristics, and the total volume of leachate to be treated.

See Table 1 for a detailed breakdown of PO*WW*ER system cost estimates.

Estimates include the following assumptions, among others:

- The treatment rate of the PO*WW*ER system is 50 gal/min (188 liters/min).
- The waste stream to be treated is landfill leachate at a Superfund site.
- The leachate will be treated 24 hr per day, 7 days per week, 365 days per year, and will be online 90% of the time. [Based on this assumption a 50 gal/min (188 liters/min) the PO*WW*ER system can treat 24 million gallons (91 million liters) annually.]
- Waste brine is considered a hazardous waste and requires off-site stabilization and disposal at an approved disposal facility.
- Labor costs associated with major equipment repairs or replacement are not included.

TABLE 1 Costs Estimates Associated with the PO*WW*ER System

Cost Categories	Estimated Costs (1993 Dollars)
Site preparation[a]	$1,100,000
Permitting and regulatory requirements	200,000
Capital equipment[a]	4,200,00[b]
Startup[a]	55,000
Labor[c]	230,000
Consumables and supplies[c]	28,000
Utilities[c]	480,000
Effluent treatment and disposal[d]	0
Residual, waste shipping, and Handling[c]	2,300,000
Analytical services[c]	42,000
Maintenance and modifications[c]	200,000
Demobilization[a]	70,000
Total one-time costs	5,600,000
Total annual overhead and maintenance	3,300,000
Total cost of 15-year project[e]	80,000,000
Costs/1000 gal treated—15 years[f]	$100
(1000 liters)	($26)

[a] One-time costs.
[b] Capital equipment cost for a modular 50-gal/min (188-liter/min) PO*WW*ER system, installed and assembled on a turnkey basis is $4 million ($1 million for a 188-liter/min system).
[c] Annual overhead and maintenance costs.
[d] Not applicable.
[e] Annual inflation rate assumed to be 5%. Capital equipment not discounted over term of project. For a 15-year project, a 50-gal/min (188-liter/min) system will treat a total of 360 million gallons (1.4 billion liters).
[f] Presented in terms of a net present value.

Information Source

D10060N, U.S. EPA, 1993

T0824

Wheelabrator Environmental Systems, Inc.

WES-PHix Process

Abstract

The WES-PHix™ process is designed to chemically stabilize ash from municipal solid waste combustion. This technology reduces the solubility of certain heavy metals in ash through the addition of soluble phosphate, lime, and water. The addition of these reagents to ash promotes the formation of metal phosphate compounds that are more resistant to leaching. The WES-PHix process produces stabilized ash that, according to the vendor, consistently passes the U.S. Environmental Protection Agency (EPA) toxicity characteristic leaching procedure (TCLP) and other regulatory leaching tests.

According to the vendor, this technology is currently commercially available.

For some wastes containing cadmium, small amounts of lime must be added.

Technology Cost

According to the vendor, the capital cost of a full-scale WES-PHix ash treatment system as a municipal waste combustion (MWC) facility will typically range from $250,000 to $750,000. WES-PHix capital costs will vary from plant to plant depending on existing facility ash handling/conditioning equipment, the equipment redundancy requirements of the MWC operator, and other factors. WES-PHix system operating costs will also vary from facility to facility. Factors affecting operating costs include bottom ash to fly ash ratio, ash chemistry, including the amount of free lime present in the scrubber residue, and ash quantities. WES-PHix system operating expenses for MWC facilities are usually between $4 and $7 per combined ash ton, with an average cost of $5 per ton. This cost includes royalties, reagents, and electricity (D16630N).

Information Source

D16630N, Lyons

T0825

U.S. Filter/Envirex Products

Ultrox Peroxone Oxidation

Abstract

Ultrox™ peroxone oxidation is an ex situ groundwater treatment technology that uses ozone and hydrogen peroxide to treat organic contaminants, including explosives. Ultrox peroxone does not require the addition of ultraviolet (UV) light to destroy organic contaminants.

RIMS was unable to contact the vendor. Commercial availability of this technology is unknown.

Technology Cost

Peroxone processes are expected to cost $0.10 to $1 (1995 dollars) per gallon of water treated (D160269, p. 5).

Information Source

D160269, http://clean.rti.org/, 1995

T0826

U.S. Filter/Zimpro Products

Powdered Activated Carbon Treatment (PACT)

Abstract

U.S. Filter's powdered activated carbon treatment (PACT®) is a sorption system used to treat water contaminated with organics, inorganics, dyes, and metals. PACT combines biological treatment and powdered activated carbon (PAC) adsorption in one unit to attain treatment standards not readily attainable with these treatments independently.

PACT can be applied to municipal and industrial waste waters as well as to groundwater and leachates containing hazardous pollutants. PACT has successfully treated various industrial wastewaters, including chemical plant, dye production, pharmaceutical, refinery, and synthetic fuel wastewaters.

PACT is a patented process. It has been installed at numerous Superfund and other contaminated sites. The technology is commercially available.

According to the vendor, PACT systems offer the following advantages:

- Uses less carbon than granular activated carbon (GAC).
- Requires lower materials costs than other activated carbon methods.
- Increases the efficiency of aerobic and anaerobic biodegradation systems.
- Improves color and odor of effluent.

In some instances, site-specific conditions prevented the demonstration of PACT systems. Some systems have encountered problems with biofouling. Iron concentrations above 10 parts per million (ppm) may host slime-producing bacteria that can clog the pores in the activated carbon. Suspended solids, pH, and temperature can also impact system performance. Metals removal may be limited. In an application at the Lowry Landfill site, manganese and cobalt were not removed during treatment.

Technology Cost

For any activated carbon system, the capital costs will be dependent on contaminant types and concentration as well as treatment goals. Capital costs will also increase in cold-weather climates, since systems may require buried piping, heating, and housing units. The major contributors to operations and maintenance (O & M) costs are treatment/replacement of spent carbon, disposal of residuals, and monitoring effluent concentrations (D11022L, p. 11–100). Also, activated carbon systems are usually part of a treatment train. Treatment costs will be highly dependent on the other systems used to deliver the contaminants to the activated carbon unit.

The estimated capital costs for a mobile PACT system range from $100,000 to $300,000. Operational costs range from less than $0.50 to over $1.00 per 1000 gal. Treatment costs are site specific. Flow rate, contaminant concentration, and the type of contamination will impact treatment costs (D19756C, pp. 2, 3). Some site-specific costs are provided below. Please refer to D19756C for additional information about the application.

At a site in Gardena, California, the capital cost for a groundwater treatment facility was approximately $375,000. The O & M costs for the first year of operation were less than $0.10/gal of treated influent (D17036F). A breakdown of O & M costs is provided in Table 1.

In 1980, O & M costs at the 3.5-million-gallon-per-day facility in Vernon, Connecticut, were approximately $0.60 per 1000 gal. The facility treats wastewater for a population of 30,000 people and an industrial base consisting of a textile dye house, a metal plating facility, and various manufacturing industries (D12857O, p. 36).

The vendor estimated that the capital costs for a 60-gal/min PACT system were $1,700,000 in 1984 dollars. Operating costs were estimated to be $435,000 (1984 dollars) per year. The vendor states that PACT systems cost less than a similar treatment system using GAC (D19955H, p. 7).

The city of Columbus, Ohio, installed a PACT water treatment system for $1.2 million. The system was purchased to remove atrazine (a pesticide) from the water supply. In 1997, Columbus spent $150,000 on powered activated carbon. Additional monitoring costs were estimated to be over $10,000 per year (D19947H, p. 11).

A 10-million-gallon-per-day wastewater treatment facility in El Paso, Texas, has operated since 1985. A PACT system operates as part of a treatment train that includes screening, the two-stage PACT system, lime treatment, two-stage recarbonization, sand filtration, ozonation, GAC filtration, chlorination, and finished water storage. Treatment costs for the entire system are $1.60 per 1000 gal (D19952E, p. 3).

TABLE 1 Operations and Maintenance (O & M) Costs for a PACT System at the Elixir Industries Site in Gardena, California (First Year of Operation)[a]

Cost Item	Quantity	Unit Cost	Daily Cost	Cost per Gallon Waste[b]
Labor	3 hr per day	$15.00/hr	$45	$0.030
Makeup PAC	25 lb per day	$0.75/lb	$19	$0.014
Chemicals	10 lb per day	$0.80/lb	$8	$0.005
GAC vessels	760 lb per year	$2.00/lb	$4	$0.002
Energy	350 kWh per day	$0.10/kWh	$35	$0.023
Sludge disposal	100 lb per day	$0.08/lb	$8	$0.005
Analytical tests	1 test per 60 days	$550 per test	$9	$0.006
Total O & M costs			$128	$0.085

Source: Adapted from D17036F.
[a]PAC, powdered activated carbon; GAC, granular activated carbon.
[b]Cost per gallon determined based on an influent flow rate of 1500 gal per day.

Information Sources

D12857O, Engineering & Management, 1982

D17036F, Lebel and Stirrat, 1994

D19756C, Joint Service Pollution Prevention Opportunity Handbook, 1997

D19947H, Ohio Citizen Action, 1999

D19952E, Water Online, 1999

D19955H, vendor literature, 1993

D11022L, Office of Water, 1990

T0827

U.S. Filter/Zimpro Products

Wet Air Oxidation

Abstract
U.S. Filter/Zimpro Products, formerly Zimpro Environmental, Inc., wet air oxidation (WAO) technology consists of aqueous-phase oxidation of dissolved or suspended organic and inorganic substances at elevated temperatures and pressures. The technology treats a wide range of hazardous organics in industrial wastewater and sludge. It can also be used as pretreatment for hazardous liquids or for carbon regeneration and sludge oxidation.

The technology has been used to treat various waste streams including municipal sludge, industrial wastewaters, acrylonitrile, metallurgical coking, and for the regeneration of carbon and is commercially available for site remediation.

The technology is best suited to relatively dilute organic contaminants in aqueous media that do not contain refractory halogenated aromatic species. The technology cannot be applied directly to organic fluids; the limited solubility of oxygen in water requires the dilution of relatively concentrated species prior to WAO treatment. The technology is not designed for the treatment of soil or debris. Long-term continuous operation may result in scale buildup in the tubes of the heat exchanger. Also, it was found that if the system becomes oxygen deficient for periods lasting longer than 10 to 15 min, sulfide will deposit in the reactor resulting in the formation of hydrogen sulfide in the exhaust gas.

Technology Cost
A wet air oxidation unit was installed in 1991 at the Sterling Organics facility in England. According to Sterling, the operational cost breakdown of running its wet air oxidation unit in 1994 was as follows: 25% labor, 4% water, 40% energy, 26% maintenance, and 4% odor control (D15559T, p. 5).

Information Source

D15559T, undated

T0828

U.S. Geological Survey

Enzymatic Reduction of Uranium

Abstract
Desulfovibrio desulfurivans (*D. desulfurivans*) is a microorganism that has been shown to convert uranium dissolved in water to a crystal form, uraninite, which can easily be removed and disposed of. Derek Lovley and Elizabeth Phillips, researchers at the U.S. Geological Survey, Reston, Virginia, found that *D. desulfurivans* and certain other microorganisms also have an affinity for metals, including uranium (D13362A, p. 26). In 1994 they were issued a patent on the enzymatic reduction and precipitation of uranium using these microorganisms shown to reduce uranium. No information on applications beyond bench-scale was available.

Several application methods are available for enzymatic reduction and precipitation of uranium. These include bioreactors, placement of the microorganisms on solid substrates for filtration, or placement in groundwater to create precipitation zones through which the contaminated groundwater migrates.

D. desulfuricans reduced uranium at concentrations as high as 24 millimoles (mM), the highest level tested; however, the reduction was slower than for 17 mM, which indicates inhibition at higher levels. It has also been established that copper inhibits *D. desulfuricans*.

Technology Cost
No available information.

T0829

U.S. Microbics, Inc.

Bio-Raptor

Abstract
Bio-Raptor™ technology uses a combination of ex situ microbial and mechanical processes to treat soils and sludges that are contaminated with hydrocarbons. The Bio-Raptor unit shreds and screens the excavated soil to increase its surface area. Then, the unit sprays and inoculates the soil with a proprietary blend of microorganisms. The soil is heaped into biopiles while the microbes degrade the contaminants. Bio-Raptor systems are commercially available and have been used for full-scale site cleanups.

According to the vendor, the advantages of Bio-Raptor are that it:

- Minimizes off-gases.
- Has a high feed rate.

TABLE 1 Capital Costs for a Transportable Bio-Raptor System

Item Description	Price
New Bio-Raptor (less shaker and Microbial Application System™)	$135,000
Microbial Application System	$35,000
Bio-Raptor shaker	$20,000
Hydrocarbon usage license—single user	$100,000

Source: From D204637.

- Is transportable.
- Treats contaminated soil on site to a level that allows treated soil to be returned to the site as fill.
- Minimizes the liability of transporting contaminated soil through populated neighborhoods.
- Is easy to operate.

All information has been supplied by the vendor and has not been independently verified.

Technology Cost

According to the vendor, the equipment costs for a Bio-Raptor system are $150,000 for a 150-ton/hr unit; $300,000 for a 300-ton/hr unit; and $500,000 for a 500-ton/hr unit. Table 1 shows the typical capital costs associated with a transportable Bio-Raptor system used to treat soil contaminated with hydrocarbons (D204615, p. 4; D204637, pp. 15, 16, 27).

Remediline™ is one of the proprietary microbial blends produced by U.S. Microbics, Inc., for use in the Bio-Raptor system. In 1999, the vendor stated that Remediline sells for $3.00 per 60-g unit or $750 per drum of 250 units. Each unit can treat approximately 1 ton of manure or yard waste. Each ton of soil contaminated with hydrocarbons requires 2.5 units of a microbial blend to remediate the soil in a single pass through the Bio-Raptor system. The vendor estimates that a typical Bio-Raptor installation would use between $500,000 and $3,000,000 in microbial blends per year (D204637, pp. 27, 33; D204579, p. 9).

The vendor estimates that treatment costs for a Bio-Raptor soil remediation would range from $15 to $100 per ton of treated soil compared with treatment costs of $100 to $400 per ton for other applicable technologies such as landfill disposal, mobile incineration, and stabilization. The vendor states that typical treatment costs using Bio-Raptor system are $3 per ton for the treatment of manure and $2.70 per ton to reduce odor, pathogens, and waste volume in yard waste (D204637, pp. 16, 28).

Information Sources

D204579, U.S. Microbics, Inc., 1999

D204615, U.S. Microbics, Inc., undated

D204637, U.S. Microbics, Inc., 1999

T0830

U.S. Naval Academy

Air Classifier with Removal of Metals from Soil

Abstract

The air classifier system is an air separation technology used to remove heavy metals from soils. This technology is a dry process that uses centrifugal force to achieve separation. The

system produces two effluent streams: one containing predominantly smaller sized particles (fine discharge) and the other containing predominantly larger particles (coarse discharge).

This process was developed by industry and refined by the U.S. Naval Academy (USNA). The equipment used is a Gayco-Reliance air separator system, built by Universal Road Machinery.

This technology is not currently commercially available.

The air classifier system has been tested as part of the U.S. Department of Energy (DOE) Heavy Metals in Contaminated Soils Treatability Project.

Technology Cost

As part of the U.S. DOE Heavy Metals in Contaminated Soils Treatability Project, total cost for the air classifier system was estimated at $1.28 (1995 dollars) per ton of material treated. Equipment costs were estimated at $151,375 and installation costs were estimated at $277,062 for a total capital cost of $378,437 or $0.18 per ton, assuming the system's operating lifetime was 10 years. Parts were estimated at $0.05 per ton, electricity was estimated at $0.05 per ton, and labor was estimated at $1.00 per ton, for a total operating cost of $1.10 per ton.

Costs considered in this estimate include the following:

- Capital equipment costs
- Installation costs
- Power costs
- Reagent costs
- Maintenance costs

Assumptions used include the following:

- The unit has a processing rate of 40 to 50 tons per hour or 300,000 tons per year.
- All operating costs are expressed in constant dollars terms; costs are not adjusted for inflation.
- Capital costs are amortized over 10 years at a 7% discount rate.
- Installation costs are estimated at 150% of equipment costs.
- Power costs are estimated using a retail electricity rate of $0.06/kWh.

Costs not included in this estimate include the following:

- Soil excavation
- Transportation
- Waste disposal
- Facility infrastructure (D14800F, pp. 41, 44)

Information Source

D14800F, MSE, Inc., 1995

T0831

U.S. Waste Thermal Processing

Model 100 Mobile Thermal Processor

Abstract

The Model 100 mobile thermal processor is an ex situ technology that treats soil contaminated with volatile organic compounds (VOCs). The processor treats petroleum-contaminated soil in a primary furnace and then incinerates any remaining combustibles in an afterburner.

Excessive moisture content can cause a slowing of the waste material feed rate.

RIMS was unable to contact the vendor. The commercial availability of this technology is unknown.

Technology Cost
No available information.

T0832

UFA Ventures, Inc.

Phosphate-Induced Metals Stabilization (PIMS) (previously called Apatite Mineral Formulations and Emplacement)

Abstract
Apatite, a natural calcium fluoride phosphate, can adsorb low to moderate levels of dissolved metals from soils, groundwater, and waste streams. Metals naturally chemically bind to the apatite, forming extremely stable phosphate phases of metal-substituted apatite minerals. This natural process is used by UFA Ventures, Inc., and is called phosphate-induced metals stabilization (PIMS). The PIMS material can by used in a packed bed, mixed with the contaminated media, or used as a permeable barrier. The material may be left in place, disposed of, or reused. It requires no further treatment or stabilization. Research is currently being conducted on using apatite to remediate soil and groundwater contaminated with heavy metals, and the technology may also be applicable to radionuclides. The technology is not yet commercially available.

Phosphate-induced metals stabilization can be used for the remediation of metals in mixed waste streams concurrently with other remediation technologies such as vapor stripping or bioremediation of organics. Using apatite to treat soils contaminated with lead, cadmium, and/or zinc can significantly reduce the amount of metals leached from the soil. The amount of apatite needed for treatment is less than 1% by weight. The reaction between metals and apatite is immediate, and the apatite can be heavily loaded with metals.

Apatite particle size cannot be much smaller than the native soil grain size or it may be washed away. Performance depends on the apatite selected; not all sources of the mineral are equally reactive or efficient. Field studies are required to establish the effectiveness of the chosen apatite source under site conditions. The order in which heavy metals are sorbed onto the apatite varies depending on the soil type. The removal of some metals is pH dependent.

Technology Cost
When the PIMS technology becomes commercially available, raw materials and labor will be the largest cost factors. Overall costs are largely dependent on the type of emplacement method used. In 1995, estimated cost for shallow soil mixing or jet injection was $35 to $50 per ton of treated soil ($39 to $55 per metric ton). Deep soil mixing would cost substantially more, and vertical barriers could be substantially less (D12985V, p. 69). The cost for the apatite itself was approximately $12 per ton of treated soil ($13 per metric ton) in 1996 (D12986W).

In a 1997 estimate provided by the vendor, the cost of permeable barrier installed during one year that operates for approximately 20 years would be about $682,000. This estimate was prepared for the Denver Creek site, in the Coeur d'Alene district of Idaho. The apatite was assumed to cover a depth of about 5 yd, and the emplacement trench was assumed to be approximately 30 yd across and 8 yd thick. The flow rate through the site was estimated to be 2 ft^3/sec. For this estimate, design costs were determined to be $48,000; feasibility study costs $110,000; health and safety costs were estimated to be $112,000; the cost of the apatite was placed at $210,000; and monitoring well emplacement and operation, including samples analyses were estimated to cost $142,000. The wall was assumed to require 1200 yd^3 of apatite at a cost of $175/ton. The removal efficiency of the unit was assumed to be 10% (D17996I, pp. 5–6).

For another nearby site, an estimate was prepared to determine the cost of using PIMS technology in three 1000-gal holding tanks. Each unit would hold approximately $4000 of apatite. Other factors included in the estimate are $13,000 for effluent monitoring, $12,000 for tank costs, $14,000 for emplacement costs, for a total cost of $43,000 (D17996I, p. 8).

In 1998, the vendor prepared a cost estimate for a lead site using a PIMS/soil mixing treatment train at a site where the soil is contaminated with 2000 ppm lead. The vendor stated that costs would range from $20,000 to $30,000 per acre to treat the soil to a depth of 50 cm. This cost was said to be a savings of 95% relative to pump-and-treat methods or standard excavation/landfilling. It was also stated to be a 50% savings over phytoremediation and electrokinetic remediation techniques. According to the vendor, actual costs will depend on many specific aspects of the site, including the metal(s) of concern, flow rates, level of contamination, the physical setup of the site, the geographical location, and other factors (D17995H, p. 12).

Information Sources

D12986W, Environtech, September 1996

D12985V, Wright et al., September 1995

D17996I, UFA Ventures, 1997 vendor web page

D17995H, 1998 vendor web page

T0833

Ultraviolet Oxidation (UV/oxidation) — General

Abstract

Ultraviolet oxidation (UV/oxidation) is a commercially available ex situ technology that destroys organic compounds from aqueous streams such as groundwater, contaminated source waters, and municipal and industrial wastewaters. High-intensity ultraviolet light is used to catalyze the formation of hydroxyl radicals from hydrogen peroxide (H_2O_2) or ozone (O_3). The hydroxyl radical reacts with the contaminants eventually forming carbon dioxide and water. The technology is most effective at treating influent streams with low contaminant concentrations where very low effluent concentrations are required.

There are several commercially available UV/oxidation technologies summarized in the RIMS library/database. These include Calgon Carbon Corporation, Perox-Pure™ (T0138), On-Site Technologies, Inc., Modular Integrated Treatment System (T0577), Process Technologies, Inc., Photocatalytic Destruction (T0625), Purus, Inc., Pulsed UV Irradiation (T0631), Ultrox International, Ultrox Advanced Oxidation Process (T0834), and UV Technologies, Inc., Photocat™ (T0853).

Ultraviolet/oxidation can be used for the treatment of groundwater contaminated with a wide variety of organic compounds including those typically resistant to oxidation using conventional technologies. Contaminants that are susceptible to destruction by UV/oxidation including aromatic hydrocarbons, pesticides, chlorinated solvents, and ordnance compounds (i.e., explosives). This technology is particularly effective for use at facilities using, storing, and/or disposing of chlorinated or nonchlorinated solvents and/or pesticides and military facilities where ordnance compounds were manufactured, used, stored, or disposed.

The system is not cost effective for influents in high concentrations nor can it easily handle contaminant spikes. According to the information provided by vendors, the UV/oxidation technology possesses the following limitations:

- The aqueous stream being treated must provide transmission of UV light (high turbidity causes interference).
- Free radical scavengers can inhibit contaminant destruction efficiency.
- The aqueous stream to be treated by UV/oxidation should be relatively free of metal ions and insoluble oil or greases to minimize the potential for fouling of the quartz sleeves.
- When UV/O_3 is used on volatile organics such as trichloroamine (TCA) the contaminants may be volatilized rather than destroyed. This would require their removal from the off-gas by activated carbon adsorption or catalytic oxidation.

Technology Cost

According to various vendors of the technology, operating costs can vary dramatically from system to system. For example, three systems (from three different vendors) were compared in treatability tests using the same contaminated groundwater from a Superfund site. Projected annual operating costs for the full-scale use of these three different systems at this site ranged from below \$500,000 to nearly \$2 million. Total capital costs were less variable, ranging from \$1.325 million to \$1.695 million (D162016, p. 8).

The variability of this technology's operating costs can be attributed to a number of factors including contaminant type and initial concentration, project cleanup goals, and the need for pretreatment of influent. In most systems, the majority of the operating costs result from UV lamp replacement and/or energy required to power the UV/oxidation system (D162016, p. 8).

Other reported or estimated operating costs for specific applications include :

- \$2.50 to \$3.00 per 1000 gal for the treatment of groundwater contaminated with 5 ppm total benzene, toluene, ethylbenzene, and xylene (BTEX).
- \$0.73 per 1000 gal to treat groundwater contaminated with 5500 μg/L trichloroethene (TCE) to an effluent concentration of 1 μg/L TCE.
- \$7.50 to \$8.10 per 1000 gal for the treatment of groundwater containing a mixture of volatile (48.6 mg/L total) and semivolatile (3.2 mg/L total) organic compounds to levels of 0.4 and 0.02 mg/L, respectively (D162016, p. 8).

Operating costs for one UV oxidation technology, the Ultrox® advanced oxidation process, varied dramatically from \$0.15 to \$90 per 1000 gal treated, depending on the type and concentration of contaminants and the desired cleanup standard. The greatest cost for the Ultrox system was the cost of electricity to operate the ozone generator and UV lamps (D123626, p. 7). A cost estimate prepared during a U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration of Ultrox technology is included in Table 1.

Based on 1998 literature, the total treatment cost for UV oxidation is approximately \$13,726,000 for a 3-year period of time. This corresponds to \$19.61 per 1000 gal of groundwater treated, or \$1830/lb of organic contaminants removed. Treatment costs include system mechanical, structural, electrical, civil, one-year operation and maintenance (O & M), and system startup costs. The annual cost of O & M averaged \$763,000. The costs are estimated based on a 3-year treatment of 7500 lb of organic compounds removed from 700 million gallons of extracted groundwater at the Bofors Nobel Superfund site, Muskegon, Michigan. Cost data are based on the available records from the facility (D18881C, pp. 35, 52).

Information Sources

D162016, NEESA, 1993

D18881C, Federal Remediation Technologies Roundtable, 1998

TABLE 1 Estimated Costs (in 1990 Dollars) Associated with Three Ultrox System Units

	By Type of System Used [Treatment Rates in gallons per minute (gpm)]		
Cost Item	20-gpm unit	100-gpm unit	250-gpm unit
Site preparation costs[a]	36,000	55,000	75,000
Permitting and regulatory costs[a]	3,500	7,500	13,000
Capital equipment costs[a]	70,000	150,000	260,000
Startup and fixed costs[a]	32,000	32,000	32,000
Labor costs[b]	6,600	6,600	6,600
Supply and consumables costs[b]	10,500	16,500	20,800
Utility costs[b]	12,000	58,000	145,000
Effluent monitoring and disposal costs[b]	3,000	3,000	3,000
Residuals and waste shipping, handling, and transporting costs[b]	1,000	5,000	7,000
Analytical costs[b]	24,000	24,000	24,000
Equipment repair and replacement[b]	4,000	22,000	33,000
Site demobilization costs[a]	2,000	3,000	4,000
Total one-time costs	143,500	247,000	384,000
Total operation and maintenance costs	61,100	135,100	239,400
Total cost	204,600	382,100	623,400
Total water treated in million gallons	10.5	52.5	131.5
Cost per 1000 gal of water treated	$19.49	$7.28	$4.74

Source: Adapted from D13629I.
[a] One-time costs.
[b] Annual operation and maintenance costs.

T0834

Ultrox International/U.S. Filter

Ultrox Advanced Oxidation Process

Abstract
The Ultrox® advanced oxidation process (Ultrox), developed by Ultrox International, is one of a group of advanced oxidation processes that use ultraviolet light, ozone, and hydrogen peroxide to destroy organic contaminants in groundwater, wastewater, drinking water, leachate, and process water. Carbon dioxide, water, salts, and harmless organic acids are the by-products of the Ultrox process. Oxidation is achieved through the direct action of ozone, hydrogen peroxide, and the highly reactive hydroxyl radical, which is created from the reaction of ultraviolet (UV) light with ozone and hydrogen peroxide. Photochemically, the UV light acts directly on target organic compounds and indirectly by speeding the creation of more hydroxyl radicals. The hydroxyl radical is an unstable molecule of hydrogen and oxygen with the ability to break the chemical bond of a target organic. Generally, the more hydroxyl radicals present in solution, the more effective oxidation will be. The technology is no longer commercially available.

The Ultrox advanced oxidation process has several advantages:

- Destroys contaminants.
- Is effective on a wide variety of contaminant types and concentrations.
- Has been commercially proven.
- Requires a small amount of energy.
- Is compact and automatic.

Advanced oxidation systems destroy dissolved organic compounds only and are most efficient when organic concentrations are less than 1% (high concentrations of contaminants will consume large quantities of ozone). Also, this technology requires considerable electrical power for the generation of UV light and ozone. Free-radical scavengers such as bicarbonate and carbonate ions limit the effectiveness of the process. Another limitation is penetration of UV light through the wastewater stream or fouling of the quartz tubes containing the UV lamps. High turbidity, solid particles, and heavy-metal ions reduce process efficiency.

Technology Cost

Advanced oxidation systems may be considered to have the same or lower capital cost than conventional air stripping or adsorption systems and a similarly high operating cost. However, accurate cost comparisons are contingent upon characterization of the waste stream (a waste stream that could require two or more conventional systems for effective treatment might require only one advanced oxidation system). Costs vary depending on the types and concentration levels of toxic organics, the degree of removal required, and the alkalinity of the water. Operating costs can range from $0.20 to $0.25 per 1000 gal treated for groundwater with chlorinated solvents to $3 to $4 per 1000 gal for highly contaminated industrial wastewaters. The greatest expense associated with the advanced oxidation systems is the cost of electricity to operate the ozone generator and UV lamps (D123626, p. 7; D124629, pp. 736–737; D12366A, p. 355).

Operating costs associated with advanced oxidation systems are a function of capacity. One Ultrox unit installed in New York for groundwater treatment of trichloroethylene (TCE) and toluene had a capital cost of approximately $1 million with a 3900-gal reactor capacity and a 250-gal/min flow through capacity. Operating costs for the unit are approximately $1.57 per 1000 gal treated at the flow rate of 250 gal/min (D124629, pp. 736–737).

Operating costs for the Ultrox advanced oxidation system have varied dramatically from $0.15 to $90 per 1000 gal treated, depending on the type of contaminants, their concentration and the desired cleanup standard (D123626, p. 7). A cost estimate prepared during a U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration of Ultrox technology is included in Table 1.

At the U.S. Department of Energy's (DOE's) Kansas City Plant in Kansas City, Missouri, a Ultrox UV/ozone/hydrogen peroxide system was used to treat up to 38 liters/min of groundwater contaminated with tetrachloroethene (PCE). The capital costs were estimated at $380,000. Operation and maintenance costs were estimated to be $5/m^3 of water treated (D19079Y, pp. 3–5).

A UV/ozone Ultrox system was used to treat wastewater contaminated with phenol and polychlorophenol (PCP) at a wood processing facility in Denver, Colorado. The capital cost for the Ultrox system was $200,000. Operation and maintenance costs for the entire remediation system were $10.92 per 1000 gal of treated wastewater. This cost estimate excludes the expenses associated with site preparation, permitting and regulatory compliance, startup, analysis, effluent disposal, and demobilization (D205505, p. C-1).

TABLE 1 Estimated Costs (in 1990 Dollars) Associated with Three Ultrox System Units

	By Type of System Used [Treatment Rates in Gallons per Minute (gpm)]		
Cost Item	20-gpm unit	100-gpm unit	250-gpm unit
Site preparation costs[a]	36,000	55,000	75,000
Permitting and regulatory costs[a]	3,500	7,500	13,000
Capital equipment costs[a]	70,000	150,000	260,000
Startup and fixed costs[a]	32,000	32,000	32,000
Labor costs[b]	6,600	6,600	6,600
Supply and consumables costs[b]	10,500	16,500	20,800
Utility costs[b]	12,000	58,000	145,000
Effluent monitoring and disposal costs[b]	3,000	3,000	3,000
Residuals and waste shipping, handling, and transporting costs[b]	1,000	5,000	7,000
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Total operation and maintenance costs	61,100	135,100	239,400
Total cost	204,600	382,100	623,400
Total water treated in million gallons	10.5	52.5	131.5
Cost per 1000 gal of water treated	$19.49	$7.28	$4.74

Source: Adapted from D13629I.
[a] One-time costs.
[b] Annual operation and maintenance costs.

Information Sources

D123626, U.S. EPA, 1991
D12366A, Fletcher, 1991
D124629, Vargas, 1994
D13629I, U.S. EPA, 1990
D17222F, U.S. DOE, 1996
D19079Y, U.S. EPA, 1998
D205505, U.S. EPA, 1997

T0835

Umpqua Research Company

Low-Temperature Aqueous-Phase Catalytic Oxidation

Abstract
Low-temperature aqueous-phase catalytic oxidation (APCO) is a technology for the destruction of aqueous-phase organic contaminants that uses a bimetallic noble-metal catalyst and oxygen gas to mineralize organic contaminants in a liquid stream. The APCO technology was developed for treatment of the wastewater in the environmental control and life support system on board a

space station and should be applicable for a variety of other, similar waste streams (D15643O, p. 2).

This technology is applicable to low-molecular-weight, polar organics such as alcohols, aldehydes, ketones, amides, and thiocarbamides. These are generally poorly removed by the baseline technology, multifiltration, and can be catalytically oxidized at relatively low temperatures (D15643O, p. 1). This technology is not yet commercially available.

Technology Cost
No available information.

T0836

Union Carbide Corporation

Triton SP-Series Surfactants

Abstract
Triton® SP-Series surfactants use both a hydrophobe and an ethoxylate chain hydrophile. The surfactants are characterized by nonionic surfactant features such as good detergency, surface activity, and wetting. When the pH of an aqueous solution that contains a Triton SP-Series surfactant is reduced, the bond between the surfactant hydrophobe and hydrophile is permanently destroyed, thus eliminating surfactancy. This product was launched commercially in December 1996 and is currently available. The surfactants cannot be used in highly acidic environments. Other compounds that might be found in the contaminated waste, such as phosphate, may interfere with the oil/water separation after surfactant deactivation. All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0837

Unipure Environmental

Unipure Process Technology

Abstract
The Unipure Environmental, Unipure process technology is a unique iron co-precipitation method for removal of heavy metals from waste streams or groundwater. It can act as a primary metal-removal system or as a polishing step to an existing treatment system. The reactor module replaces the neutralization tank in a conventional wastewater treatment system. The process produces solids that are extremely insoluble in water and mild acid solutions.

Iron is a natural coagulant that agglomerates fine and colloidal metals in water. It is a natural absorbent of heavy metals present in water, and its solids are more dense than other metal hydroxide precipitates.

According to the vendor, the Unipure technology is capable of treating wastewater from metal finishers, battery manufacturers, incinerators, metal smelters, and galvanizers. Chrome plating solutions, spent plating baths, acids, phosphating solutions, chelating solutions, alkaline cleaners, and flux baths can also be treated with this technology. Other applications may include contaminated groundwater or landfill leachate. It is able to treat both dilute and concentrated waste streams.

This technology is currently commercially available from Unipure Environmental.

Technology Cost
No information available.

T0838

United Retek Corporation

Asphalt Emulsion Stabilization

Abstract
United Retek Corporation (URC) has developed asphalt emulsion stabilization technology for the ex situ treatment of soils contaminated with organic compounds and heavy metals. In this ambient temperature technology, the targeted contaminants are stabilized and solidified in an asphalt emulsion. According to the vendor, this emulsion can be used for pavement after the material has been cured. The technology has been used in full-scale site remediation projects and is commercially available.

United Retek Corporation states that asphalt emulsion stabilization has the following advantages:

- No materials are removed from the property as waste, and the final waste form can be sold as a product or used on-site.
- Ambient temperature operation limits volatilization of contaminants.
- It provides a rapid, economical treatment.

The vendor claims that asphalt emulsion stabilization can treat soils with up to 60,000 parts per million (ppm) total petroleum hydrocarbons (TPH). In New York and New Jersey, permitting of the asphalt emulsion process is not allowed for sites where TPH levels are above 30,000 ppm. U.S. Environmental Protection Agency (EPA) regulations allow for the technology to be applied to soils with polychlorinated biphenyl (PCB) concentrations of 10 ppm for controlled-access sites and 25 ppm for uncontrolled-access sites.

Technology Cost
United Retek Corporation's asphalt emulsion stabilization process was used at an active paper company in Pawtucket, Rhode Island. The company wanted to expand its facility at the site; however, lead contamination was discovered in the proposed 43,000-ft^2 expansion area. Soil lead concentrations were in excess of 100 ppm at some locations within the area. Asphalt emulsion stabilization was used over 5 days to treat 2000 yd^3 of soil. Total treatment costs were $80,000, or 2000 yd^3 of soil treated at $40/$yd^3$. It was estimated that excavation and removal costs at the site would have been $200 to $250/$yd^3$ of soil (D21950L, pp. 2, 3).

Information Source

D21950L, U.S. EPA, undated

T0839

United States Army Environmental Center (USAEC)

Hot-Gas Decontamination (HGD)

Abstract
Hot-gas decontamination (HGD) is a thermal treatment technology designed to treat process equipment requiring decontamination before reuse. It is also applicable for explosive items,

such as mines and shells, being demilitarized or scrap material contaminated with explosives. Compounds that have been successfully treated by hot-gas decontamination include 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), and tetryl.

The technology involves raising the temperature of the contaminated equipment or material to 500°F for a specified period of time. The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants. The method is designed to eliminate stockpiled waste that would otherwise require disposal as a hazardous material. The HGD system can be built in a permanent position for use at a single location, or it can be built and used as a mobile unit.

The following factors may limit the applicability and effectiveness of this technology:

- Associated costs are higher than those of open burning.
- Flash chamber design must take into consideration possible explosions from improperly demilitarized mines or shells.
- The rate at which equipment or material can be decontaminated is slower than that for open burning.

In addition, the technology should not be used on materials containing friable asbestos, polychlorinated biphenyls (PCB) or lead-based paints, galvanized sheet metal (when heated above 700°F), electrical wiring, wood, vermin excrement, or highly concentrated explosives (e.g., explosives confined within a pipe).

Although this technology is not commercially available from the United States Army Environmental Center (USAEC), the individual components are generally commercially available and assembly plans with guidance are available.

Technology Cost

The U.S. Army claims that HGD gained a reputation for being expensive during the research and development stage. Several factors contributed to increased costs during this period, including:

- First-time demonstration expenses
- Redundant safety and environmental systems
- Testing of multiple operational variables
- Additional instrumentation needed in the research and development setting
- Added safety features required for chemical warfare agent treatment (D19338Y, p. 2)

According to the Army, HGD is now less expensive than incineration, an alternate treatment technology. The Army claims that HGD is also cheaper than most comparable chemical and steam-cleaning technologies (D19792G, p. 1). A pilot-scale HGD unit at Hawthorne Army Depot in Nevada can decontaminate a ton of 175-mm shells for approximately half the cost of treatment in a flash furnace. The depot further reduces technology costs by selling the decontaminated casings for scrap metal (D19792G, p. 2).

The Army claims that a 1200-ft^2 building containing contaminated equipment would cost \$222,000 to treat using a HGD system without the exit-gas treatment stages. This cost translates to \$185/ft^2. Due to the economies of scale, the cost of additional treatment at the same site would then be reduced to \$11/ft^2. When adding the exit-gas treatment stages, the cost of treating a 1200-ft^2 building using a HGD system increases to \$370,000, or \$308/ft^2. The cost of additional treatment at the same site would decrease to \$13/ft^2 (D19338Y, p. 7).

At the Alabama Army Ammunition Plant Site in Alpine, Alabama, capital costs for a transportable HGD system were \$689,500. Operating costs at this site were \$3337 (D213296, p. 2). These higher costs may be a reflection of the factors listed above.

Information Sources

D19792G, Buckley, 1997
D213296, Federal Remediation Technologies Roundtable, undated
D19338Y, Kelso, undated

T0840

United States Department of Agriculture Forest Service — Forest Products Laboratory

Phanerochaete sordida

Abstract
The United States Department of Agriculture Forest Service—Forest Products Laboratory is researching the use of *Phanerochaete sordida*, a specific variety of white-rot fungus to degrade pentachlorophenol (PCP) and polycyclic aromatic hydrocarbon (PAH) components of creosote in soil. The technology is not currently commercially available, and the developers are no longer working on this technology.

White-rot fungus is a lignin-degrading fungus. Lignin, found in wood, is an exceptionally stable molecule and is very resistant to degradation. White-rot secretes enzymes that are able to degrade lignin, as well as certain environmental contaminants. When used in remedial activities, white rot is grown on a substrate (often sawdust, wood chips, or grain dust) supplied with nutrients, and mixed into the contaminated soil.

Based on the results of field tests, the ability of *Phanerochaete sordida* to degrade PAH constituents of creosote appears to be severely limited. The exact reasons for this are unknown. Its ability to degrade PCPs to regulatory levels has also not yet been demonstrated.

From a physical standpoint, the effectiveness of *Phanerochaete sordida* is influenced by soil temperature, moisture level, and nutrient and substrate levels.

Technology Cost
No available information.

T0841

University of Akron

Sonochemical Destruction

Abstract
Sonochemical destruction is a process for the destruction of volatile organic compounds (VOCs) in water using ultrasound. The technique is being researched for the treatment of contaminated ground and process water. Sonochemistry in liquids is the inducement of chemical reactions by the application of ultrasound energy; acoustic cavitation results in the formation of “hot spots” of intense temperature and pressure that cause the destruction of VOCs.

Bench-scale testing has indicated that the temperature and initial pH of the solution have little effect on destruction rates. No chlorinated organic products were found as a result of treatment using sonochemical destruction. Laboratory headspace analyses indicate that 5% or less of VOCs are lost to volatilization during treatment.

A closed system would be required for a large-scale implementation of the technology to capture volatilized VOCs.

Technology Cost
No available information.

T0842

University of California, Riverside

Carvone-Induced Bioremediation

Abstract
Carvone is a chemical component of the spearmint plant that has been shown to enhance the growth and ability of *Arthrobacter* bacteria to degrade polychlorinated biphenyl (PCB). Until this discovery the only known method of stimulating the bioremediation of PCBs was addition of biphenyl to the soil; however, biphenyl is itself a toxic substance.

Carvone is used as a flavoring agent in breath mints and chewing gum. The discovery of its affect on PCB-degrading microorganisms was made by Eric Gilbert, a graduate student at the University of California, Riverside, studying under Dr. David Crowley. Gilbert developed a set of methods for rapidly screening plant extracts for ability to stimulate naturally occurring organisms to degrade PCBs, which led to his discovering the ability of carvone. The research was funded by the University of California Toxic Substances Teaching and Research Program.

Thus far the technology has not advanced beyond bench-scale tests that confirmed the basic premise (carvone's ability to enhance biodegradation). The next step, according to Crowley, will be to develop technology to improve the survival and activity of the PCB-degrading bacteria in the field. One possibility is the application of carvone-induced bacteria using an automated, field-based fermentation system. Another possibility involves the use of surfactants along with the carvone and/or bacteria to increase the bioavailability of the soil-bound pollutants. In some cases the bacteria themselves may produce biosurfactants during growth on hydrophobic substrates.

Although carvone has been shown to induce PCB degradation, it cannot act as a sole carbon source. Also, the PCBs partition to the organic fraction of the soil matrix and the bioavailability of PCBs to the degrader organism need to be increased.

Technology Cost
No available information.

T0843

University of Cincinnati Department of Civil and Environmental Engineering

Reductive Electrolytic Dechlorination

Abstract
A biofilm electrode reactor (BER) has been used by researchers at the University of Cincinnati to dechlorinate pentachlorophenol (PCP), a halogenated organic used in wood and leather treatment. This technology is not commercially available. All information is from the developer and has not been independently verified.

Technology Cost
No available information.

T0844

University of Connecticut

Contaminant Absorption and Recovery

Abstract
The contaminant absorption and recovery (CAR) technology treats volatile organic compounds (VOCs) in gas streams from such processes as soil vapor extraction, air sparging, and air stripping. The contaminated gas stream passes through an absorption solvent, which is a nonvolatile

organic compound. The gas-phase contaminants are transferred into the solvent. The solvent is subsequently stripped of the VOCs. The results of the laboratory study suggest that high temperatures and low pressures should be used for desorption. The stripped VOCs are now concentrated in a low-flow gas stream, are passed into a condenser, and are collected in a liquid phase. The technology has been used at one site in full scale and may become commercially available during 1997.

Water vapor decreases the efficiency of this technology.

Results of pilot-scale operation indicated acceptable removal efficiencies and cost-effective performance, compared to granular activated carbon (GAC) or thermal destruction processes. Near zero ambient discharge is possible.

Technology Cost

No available information.

T0845

University of Dayton Research Institute

Photo-thermal Detoxification Unit

Abstract

The University of Dayton Research Institute has developed a photo-thermal detoxification unit (PDU) that can completely destroy vapor-phase organic contaminants from soil, sludge, and aqueous streams. The PDU is a patented technology that is available for licensing. Engineering plans for construction of a PDU are commercially available. The technology has not been demonstrated on a field scale but has been used in laboratory studies of simulated wastes.

TABLE 1 Estimated Materials Costs for Photo-thermal Detoxification Unit

Item	Cost	Expected Life	Annual Cost
Carbon steel shell	\$20,800[a]	20 years	\$1,040
Firebrick insulation	\$1,370[b]	5 years	\$274
Lamp wells	\$8,400	2 years[c]	\$4,200
Lamp ballasts	\$8,500	4 years[d]	\$2,125
Support structure	\$8,500[e]	20 years	\$425
Subtotal	\$47,570		\$8,064
Lamps	\$3,000	6 months[f]	\$6,000
Subtotal	\$50,570		\$14,064
Electrical service[g]			\$22,500
Grand Total			\$36,564
Hourly cost[h]			\$7.31

[a] Assuming \$86/ft^2.
[b] Assuming \$1.44 per square foot-inch.
[c] Assuming 10,000-hr life and 5000 hr of operation per year.
[d] Assuming 20,000-hr life and 5000 hr of operation per year.
[e] Assuming support structure and equipment is 20% of the chamber cost less support.
[f] Assuming 2500-hr life and 5000 hr of operation per year.
[g] Assuming \$0.50/kWh and 5000 hr of operation per year.
[h] Assuming 5000 hr of operation per year.

The photo-thermal detoxification unit uses photo-thermal reactions conducted at temperatures higher than those used in conventional photochemical processes (200 to 500°C, rather than 20°C) but lower than combustion temperatures (typically greater than 1000°C). At these temperatures the developer claims that photochemical reactions are energetic enough to destroy wastes quickly and efficiently without producing complex and potentially hazardous by-products.

The technology cannot handle metals.

Technology Cost

Table 1 contains 1995 estimated materials costs for a single photo-thermal detoxification unit chamber fitted with six 15-kW medium-pressure mercury lamps. Labor and licensing costs were not included (D117317, p. 9).

The inventors estimate the unit will cost $27.00/hr to operate, processing 30 tons of contaminated soil per hour. Equipment costs would average an additional $17.00/hr (D15604H, p. 1–2).

Information Sources

D117317, SITE Emerging Technology Summary, August 1995
D15604H, Technology Access, date unknown

T0846

University of Massachusetts

Oleophilic Suction Lysimetry

Abstract

Oleophilic suction lysimetry (OSL) uses a membrane-covered oil recovery lysimeter to recover non-aqueous-phase liquids (NAPLs) from contaminated vadose zone soil. The lysimeter is placed into the soil to intercept a region of soil contaminated by NAPL. Vacuum pressures applied to the lysimeter draw NAPL through the membrane. Recovered NAPL is then conveyed to the ground surface for storage prior to disposal.

Oleophilic suction lysimetry is unique as a remediation technology in that it focuses on the selective removal of pure NAPL contaminant while excluding the removal of air and water. Bench-scale experiments were performed at the University of Massachusetts using coarse soil, loam, and diatomaceous earth. Although it was shown that the technology could selectively remove NAPL such as dodecane from wet soils, the experiments also displayed the severe limitations of the OSL technology. NAPL recoveries were too low to make OSL an attractive in situsoil remediation technology. This technology is not currently commercially available.

Technology Cost

No available information.

T0847

University of New South Wales

Upflow Washing

Abstract

Upflow washing is an in situtechnology being developed for the treatment of sandy or silty soils contaminated with organic or metal contaminants. The technology uses an upward fluidizing

flow of water and/or gas introduced into the zone of contamination. The technology is not yet commercially available.

Technology Cost
No available information.

T0848

University of Southern California

Hybrid Microfiltration–Bioactive Carbon Process

Abstract
Researchers at the University of Southern California, Los Angeles, have developed a technology called the hybrid microfiltration–bioactive carbon (MF-BACP) process, for the ex situ treatment of contaminated groundwater.

The technology is a combination of biodegradation, adsorption onto activated carbon, and microfiltration. It uses microbes grown on active powdered carbon as a prefilter and to degrade organics and a cross-flow membrane filter to remove biomass, viruses, and suspended impurities.

The technology has been patented but is not yet commercially available. However, the developer is seeking to negotiate with industry to commercialize the process.

Technology Cost
No available information.

T0849

University of Washington

Metals Treatment by Adsorptive Filtration

Abstract
The University of Washington has developed a technology for the removal of metals from aqueous streams by coating sand with a thin layer of iron oxide. This technology is not currently commercially available and has only been tested in research studies.

The modification of the sand surface allows the grains to simultaneously adsorb soluble heavy metals and remove particulate metals by filtration in a column packed with the media. Important factors to the performance of the adsorbent include pH of the solution to be treated, empty bed detention time (EBDT), and the presence of complexing agents, oil, surfactant, and biodegradable substances.

After treatment has proceeded for a period of time, either the coating reaches its maximum capacity to remove metals or the filter requires backwashing. At this time, the column can be backwashed to recover particulate metals from the column, and an acidic solution can be used to recover the adsorbed metals, thereby regenerating the column. Because the ferrihydrite is trapped on the sand particles, only the contaminant metals and nonferrihydrite are released. Thus the need to dispose of large amounts of iron oxide with the metal sludge, one of the main drawbacks of a conventional treatment process, is eliminated.

The effects of other contaminants in the feed stream was tested using ammonia and ethylenediaminetetraacetic acid (EDTA). While ammonia had little effect on the effectiveness, EDTA affected efficiency significantly. When the metals were complexed with EDTA, they broke through almost immediately, making the capacity of the media to remove metals not significant at either pH 10.0 or 4.5. Also, sodium lauryl sulfonate is a surfactant that might interfere with adsorption filtration.

An attempt was also made to investigate the behavior of media on which biogrowth had occurred. The biofilm was found to reduce the media's capacity for metals by about 50%

Technology Cost
No available information.

T0850

UOP, Inc.

Ionsiv IE-911 Ion Exchange Resins

Abstract
The Ionsiv® ion exchange resins are extraction technologies used to separate radionuclides from alkaline wastewater in the presence of competing cations. These resins include Ionsiv IE-910 and Ionsiv IE-911, which are manufactured using a new class of crystalline silicotitanates (CSTs) invented by researchers from Sandia National Laboratory (SNL) and Texas A & M University. CSTs demonstrate high distribution coefficients in acidic, neutral, and alkaline solutions with high concentrations of competitive ions such as sodium and potassium. The affinity of CSTs for strontium in neutral or alkaline wastes is also high.

Ionsiv CST resins have been used in full-scale systems and are commercially available.

Researchers claim the following advantages of Ionsiv CST technology:

- Removes cesium in pH ranges from 1 to 14 and strontium in pH ranges from 14 to neutral.
- Offers the only technology that can remove cesium and strontium from alkaline solutions in the presence of competing cations without additional treatment steps.
- Allows for simpler processing of wastes since it is a nonregenerative removal technology.
- Processes larger volumes of waste than regenerable, organic ion exchange resins.
- Produces a smaller volume of contaminated waste, reducing disposal costs.

Process pH, sodium, calcium, and nitrate concentrations, plugging of the ion exchange column, lot variance, and the presence of binders can affect process efficiency. Ionsiv IE-911 does not remove anionic radioactive ions such as technetium. The resins are designed for one-time use and must be replaced when loaded. The waste acceptance criteria at the resin disposal facility may limit the loading of the CST resin. Size constraints of the cesium removal system (CRS) may limit system flow rates.

Technology Cost
The vendor estimates that the cost of the Ionsiv IE-911 ion exchange resin ranges from $90 to $110/lb (in 1995 dollars) (D19431U, p. 13).

In 1995, the total cost to remediate 187,000 m^3 of liquid high-level radioactive waste (HLW) at the Hanford site in Richland, Washington, was estimated to be $6.543 billion. Approximately $163 million was allocated to purchase the resin. The costs of the facilities and operations were estimated at $530 million. The remaining $5.850 billion were associated with the vitrification and disposal of the used resin (D19431U, pp. 5, 11).

Between June 1996 and July 1997, a full-scale CRS was demonstrated at the U.S. Department of Energy's (DOE's) Melton Valley Storage Tank on the Oak Ridge Reservation in Tennessee. The capital costs for the demonstration were estimated at $9.1 million. This estimate

TABLE 1 Cost Estimate for Treatment of Supernatant at the Oak Ridge Reservation Using the Cesium Removal System

Cost Item	Cost in Millions of Dollars
Research and development	4.2
Capital costs	5
Operating costs	5.6
Ion exchange resin disposal	1.7
Decommission	0.5
Final treatment and disposal of supernatant	13.0
Total cost	30

Source: Adapted from D20941G.

included \$4.2 million for research and development, \$3.8 million for initial system equipment and installation, and \$1.1 million for system modification (D20941G, p. 11).

Based on the Melton Valley Storage Tank demonstration, the DOE calculated the cost of treating the supernatant at the Oak Ridge Reservation (D20941G, pp. 12, 13). These costs are displayed in Table 1.

Information Sources

D19431U, DeMuth, 1996

D20941G, U.S. DOE, 1999

T0851

UOP, Inc.

Ionsiv TIE-96 Ion Exchange Resins

Abstract

UOP molecular sieves (UOP) has developed the Ionsiv® family of ion exchange resins for the extraction of radionuclides from wastewater. Ionsiv TIE-96 is composed of a titanium-coated zeolite (Ti-zeolite) and is used to separate plutonium, strontium, and cesium from alkaline supernatant and sludge wash solutions. The technology was developed by Pacific Northwest Laboratory (PNL) for use at the West Valley, New York, nuclear waste facility. The technology is commercially available.

Researchers claim that Ionsiv TIE-96 can remove 99.9% of the plutonium, strontium, and cesium from waste solutions, allowing for wastes to be divided into separate low-level and high-level radioactive waste streams, where they can be safely and efficiently processed for disposal.

As temperatures are decreased from 25°C, cesium is removed more efficiently, but the removal efficiency of plutonium is decreased. Plutonium extraction efficiency is also affected by differences in process pH.

Technology Cost

No available information.

T0852

U.S. EPA Risk Reduction Engineering Laboratory

Mobile Volume Reduction Unit

Abstract
The mobile volume reduction unit (VRU) is a soil washing technology that rids organic contaminants and heavy metals from soils, sludges, and sediments by suspending them in a wash solution and reducing the volume of contaminated material through particle size separation and solubilization. It was developed by the U.S. Environmental Protection Agency's (EPA's) Risk Reduction Engineering Laboratory (RREL), with assistance from Foster Wheeler Enviresponse, Inc. The VRU was designed to be an EPA testing platform and to perform treatability studies. It is not intended for commercial use.

The VRU is designed to treat soils contaminated with organic contaminants and heavy metals. The system is flexible, and allows for changes in the process train, treatment temperature, surfactant addition, and the use of steam for stripping.

Technology Cost
All estimated costs for the full-scale VRU are based on results from the pilot-scale unit tested at the U.S. EPA's Superfund Innovative Technology Evaluation (SITE) program, and all costs are given in 1993 U.S. dollars. At this demonstration, the unit treated 100 lb of soil per hour. The full-scale unit is expected to have a treatment capacity of 10 tons per hour (tph).

The treatment cost to remediate 20,000 tons of contaminated soil using a 10-tph VRU is estimated to be $137 per ton, if the system is online 90% of the time. Treatment costs increase as the online factor decreases. Projected unit costs for a smaller site (10,000 tons of contaminated soil) are $171 per ton; projected unit costs for a larger site (200,000 tons) are $106 per ton for a 10-tph VRU and $72 per ton for a 100-tph VRU. These costs do not include site preparation, permits, regulatory requirements, monitoring, waste disposal, sampling and analysis, or posttreatment restoration, which are considered to be the obligation of the responsible party or site owner. Also not included in these estimates is profit on the part of the vendor (D10056R, pp. 16, 24).

Total equipment cost for the 10-tph unit was estimated to be $1,240,000. Add to this freight, taxes, installation, engineering, instrumentation, piping, electrical work, and supervision, and the total fixed capital investment was projected to be $3,110,000 (D10056R, p. 19). The highest costs are those incurred by site preparation, startup/fixed costs, and labor; each of these represents roughly 20% or more of total operating costs (D10056R, p. 22). A detailed breakdown of costs is available on pages 22 to 24 of D10056R.

Information Source

D10056R, U.S. EPA, 1993

T0853

UV Technologies, Inc.

UV-CATOX Technology

Abstract
UV-CATOX is an ex situ technology that involves the oxidization of low to moderate levels of toxic organic compounds in industrial wastewater and groundwater. The UV-CATOX process

uses a chemical oxidant, ultraviolet (UV) radiation, and a photocatalyst to drive photochemical oxidation. According to the vendor, less than 50 sec of exposure to the system's UV light is required to oxidize 90% of certain organic compounds. The vendor claims that UV-CATOX has treated many contaminants including ethers; benzene, toluene, ethylbenzene, and xylene (BTEX); phenol; trichloroethane (TCA); dichloroethene (DCE); tetrachloroethene (PCE); and trinitrotoluene (TNT).

According to the vendor, UV-CATOX has the following advantages:

- Organic contaminants are completely broken down, resulting in no toxic by-products.
- The use of oxygen makes the process more cost-effective than alternative technologies.
- The process can treat organic contaminants in groundwater with low concentrations and organic contaminants in industrial wastewater with concentrations over 10,000 ppm.

The technology may not be cost effective for treating organic contaminants at concentrations greater then 50,000 ppm.

Technology Cost

According to the vendor, total operating costs for the treatment of industrial wastes can be estimated using the projected costs for electricity, lamp replacement, and hydrogen peroxide. Vendor-supplied cost components and projected operating costs are presented in Table 1. These projections are based on the following assumptions:

- Electricity at $0.05/kWh
- Hydrogen peroxide at $0.75 per dry pound (injected at the stoichiometric ratio for the feed material)
- Lamp replacement at quantity prices
- 90% contaminant removal (D16035A, p. 5)

The vendor estimates that the general operating costs of the UV-CATOX technology can be less than $1 per 1000 gal for waste containing 10 ppm organics. For waste containing 10,000 ppm organics, costs are estimated to be several hundreds of dollars per 1000 gal. These estimates include the cost of electricity, the replacement cost of the UV lamps, and the cost of hydrogen peroxide (D16035A, p. 1).

TABLE 1 Vendor-Supplied Operating Costs for Industrial Strength Waste Streams

Source of Material	Initial Contaminant Concentration	Electricity and Lamp Replacement Cost ($/1000 gal)	Hydrogen Peroxide Cost ($/1000 gal)	Total Operating Cost ($/1000 gal)
Textile mill (Sample 1)	740 ppm total organic carbon (TOC)	162	40	202
Textile mill (Sample 2)	100 ppm TOC	13	5	18
Specialty chemical manufacturer	11,925 ppm TOC	213	633	846
Environmental consultant	2,666 ppm chemical oxygen demand (COD)	24	35	59

Source: From D16035A.

According to the U.S. Environmental Protection Agency (EPA), UV-CATOX capital costs can vary from the $20,000 to $50,000. These costs are dependent on the system flow rate, contaminant concentrations, and effluent limits. System operating costs can be as low as $0.20 per 1000 gal or as high as $10 to over $100 for "high-strength" industrial waste streams (D224306, p. 2).

For a 3-year remediation project, the total treatment cost for another vendor's UV oxidation system was approximately $13,726,000. This value corresponds to $19.61 per 1000 gal of groundwater treated, or $1830/lb of organic contaminants removed. Treatment costs included system, mechanical, structural, electrical, civil, one-year operation and maintenance (O & M), and system startup costs. The annual cost of O & M averaged $763,000. Costs are based on the 3-year treatment of 7500 lb of organic compounds removed from 700 million gallons of extracted groundwater at the Bofors Nobel Superfund site, Muskegon, Michigan. Cost data are based on the available records from the facility (D18881C, pp. 35, 52).

Information Sources

D16035A, UV Technologies, Inc., date unknown

D18881C, Federal Remediation Technologies Roundtable, 1998

D224306, U.S. EPA, undated

T0854

Vance IDS, Inc.

Vance Incandescent Disposal System (IDS)

Abstract

The Vance incandescent disposal system (IDS) is a patented, commercially available, ex situ technology for the treatment of biohazardous medical and other hazardous wastes.

The technology changes the composition of the waste to render it nonhazardous. This change is achieved by exposing the waste to electrically generated intense incandescent heat in an inert plasma ion cloud and controlled argon atmosphere. By-product gases generated are used to facilitate the decomposition of waste and to collect reusable residue. The IDS was originally designed for the treatment of medical wastes, but the vendor expects to market the technology in other areas as well. The technology cannot treat asbestos or radioactive waste.

Technology Cost

The vendor estimates costs for operating labor, utilities, maintenance and repair, treated residue disposal, and disposal of waste items excluded from the current system to be between $0.05 and $0.14/lb, depending on the size of the machine. This estimate is based on 60 hr per week operation, and utilities costing $0.06/kWh of electricity, $0.096/gal of water, and $0.048/gal of sewer discharge (D14408B, p. 4). The vendor estimates the price of an IDS unit to be from $450,000 to $5,000,000, with capacity ranges from 100 to 6000 lb/hr (personal communication, Brian Bateson, Vance IDS, 12/3/97).

Full-service agreements are available through the vendor that allow the customer to pay only for poundage processed. No capital equipment needs to be purchased. The vendor expects 100% maintenance and upgrades to be performed through the life of the machine (D14408B, pp. 2, 4).

Information Sources

D14408B, Vance IDS, Inc., November, 1996

Personal communication, Brian Bateson, Vance IDS, December 3, 1997

T0855

Vapor-Phase Biofiltration — General

Abstract
In recent years the emission into the atmosphere of volatile organic compounds (VOCs) has undergone increased regulation from the U.S. Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA), and other government agencies due to potential human health hazards. Conventional methods for treating VOCs include adsorption on solids, adsorption in solvents, incineration and catalytic oxidation. An alternative to these methods is biological degradation in gas-phase biofilters.

Biofiltration is an air pollution control technology that utilizes microorganisms to oxidize volatile organic and certain inorganic compounds to carbon dioxide, water, and mineral salts. The microorganisms are immobilized on a filter medium through which a gas stream is passed. Given an adequate exposure time (called residence time) microorganisms can then biodegrade the contaminants. The organic contaminants can often serve as the carbon nutrient source for microbial growth.

The technology is typically applied to gas streams with VOC concentrations of 1500 ppm or less, but sometimes as high as 5000 ppm.

Biofiltration of contaminants in a gas stream through a solid-phase reactor is a well-established technology in several European countries, most notably The Netherlands and Germany. The experiences in Europe have shown that biofiltration has economic and other advantages when applied to off-gas streams that contain only low concentrations of air pollutants that are easily biodegraded. Biofilters are currently commercially available in the United States and have been used in multiple full-scale applications. Information on specific commercially available biofilters may be found in the RIMS technology summaries of the Biocube™ (T0039), Bioton (T0033), Biogenie (T0104), Bohn (T0130), and Basys (T0079) biofilter technologies. In addition to these vendor-specific technologies, RIMS contains general summaries for Peat/Compost (T0595), Soil (T0309), and Methanotrophic (T0520) biofilter technologies.

The following factors may limit the applicability and effectiveness of biofiltration:

- The rate of influent air is constrained by the size of the biofilter.
- Fugitive fungi may be a problem.
- Low temperatures may slow or stop removal unless the biofilter is climate controlled.

Biofilters do not treat metals and are limited to treating contaminants that are susceptible to biodegradation by the microorganisms that are present in the biofilter media.

In some cases, contaminants can become sorbed onto the filter media. In such cases higher readings may be observed for contaminant removal from the gas stream; however, the contaminants have not been degraded and the media itself becomes a process waste stream.

Technology Cost
Information on capital and operating cost for various biofilter systems installed in Germany and The Netherlands has been reported. These data suggest total operating costs of approximately \$1.50 per 100,000 ft^3 of off-gas, depending on the size of the filter. Cost figures obtained from systems installed in the United States of \$0.30 to \$0.60 per standard cubic feet do not include the replacement of the filter material and also reflect the generally lower cost of electricity in the United States.

Capital costs for open single-bed filters installed in Germany are estimated at \$25 to \$95/ft^2 of filter area depending on the size of the system. Costs for filters with multiple beds are about twice as high. For open single-bed filters installed in the United States, cost per square of filter

TABLE 1 Cost Comparison of Air Pollution Control Technologies (1991 U.S. dollars)

Technology	Total Cost ($) per 10^6 ft^3 of Air[a]
Incineration	130
Chlorine	60
Ozone	60
Activated carbon (with regeneration)	20
Biofiltration	8

Source: From D14012V, Bohn, 1992.
[a]Costs obtained from B. Jaeger, and J. Jeger, "Geruchs-bekaempfung in Kompostwerken am Beispiel Heidelberg," Muell und Abfall, pp. 48–52 (Feb. 1978) and converted/updated to 1991 U.S. dollars.

area is estimated at $55 to $90, and with closed systems, from $90 to $500/ft^2, depending on size and degree of process control (D15268L, p. 1052).

Another source gives cost estimates for non-vendor-specific biofilters that range from $5 to $10/kg of contaminant ($2.27 to $4.54/lb) (D10940A, p. 4–28).

Biocube™ (T0039) is a commercially available off-gas treatment system. A Biocube was installed at a domestic wastewater pumping facility in June 1995 at a cost of $15,000. The pumping facility treats approximately 200 m^3 of water per day (50,000 gal per day) (D13550C, pp. 1–4). At a silver reclamation facility in Duval County, Florida, a Biocube biofiltration system used to treat vapors containing mercaptans (mainly 4-mercapto-4-methyl-2-pentanone) cost $18,000 (D13551D).

Treatment with another commercially available system, the Bohn Biofilter (T0130), is estimated to cost $5 to $10/kg of waste. Factors that have a significant effect on the unit price are the quantity of waste, the target contaminant concentration, the initial contaminant concentration, and the targeted final concentration of the treated contaminant. These cost estimates do not always include all indirect costs (D10048R, p. 28). According to this vendor, biofiltration is one of the most affordable air treatment technologies on the market (D14012V, p. 37). Table 1 compares the costs of various off-gas treatment technologies.

Information Sources

D14012V, Bohn, 1992

D10048R, 1994

D13551D, EG & G Biofiltration, November 1996

D13550C, Singleton et al., February 1996

T0856

Vecor Industries, Inc.

Apollo Greenzyme

Abstract

Apollo Greenzyme is a commercially available concentrated solution of enzymes for use in remediation of hydrocarbon-contaminated solids and sediments and separation of hydrocarbons

from water. This technology is available from Vecor Industries, Inc. (formerly The Storehouse Corporation). All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0857

Vendor Unknown

Calocroma Soil Washing

Abstract
The transportable Calocroma soil washing technology is an ex situ process that uses continuous extraction with an unspecified extraction fluid to extract hydrocarbons and solvents from soils.

According to information in the U.S. Environmental Protection Agency (EPA) VISITT 4.0 database, the technology can effectively treat soils ranging from coarse sands and gravels to fine clays. The developer also claims that the soil can treat sediments and can potentially treat nonmunicipal sludge and solids (e.g., slag).

The technology developer claims that the technology can treat most organic and inorganic compounds, as well as metals, although testing has primarily been restricted to petroleum hydrocarbons, pesticides, solvents, lead, and copper.

According to the technology developer, the Calocroma soil washing technology has been used in the following industries: gasoline/service stations, pesticide manufacturing/use, petroleum refining and reuse, and wood preserving. The Calocroma soil washing system can operate in most weather conditions, except extremely cold temperatures. RIMS was unable to contact the technology developer.

All information was supplied by the vendor and has not been independently verified. This technology was developed in conjunction with On-Site Technologies, Inc. However, this technology is no longer commercially available from this vendor.

Technology Cost
The technology developer claims that the estimated cost for the Calocroma soil washing technology ranged from $40 to $120 per ton of waste treated (D10402P, p. 13).

The Calocroma soil washing technology reduces transportation and soil disposal costs by reusing the treated soil on site (D10402P, p. 2).

Among the factors that affect the cost of the technology are (D10402P, p. 13):

- Target contaminant concentration
- Initial contaminant concentration
- Soil characteristics
- Residual waste characteristics
- Waste quantity
- Soil moisture content
- Depth to groundwater
- Labor rates
- Utility/fuel rates

Information Source

D10402P, VISITT 4.0

T0858

Versar, Inc.

Chemical Reduction of Hexavalent Chromium Contaminated Soils

Abstract

Versar, Inc., has developed a method for the ex situ remediation of soils contaminated with hexavalent chromium. In this process, soil is mixed with a sodium bisulfite solution to chemically reduce the chromium to the less toxic trivalent form.

This technology was successfully demonstrated for the California Environmental Protection Agency, Department of Toxic Substances Control, at a site in Bakersfield, California, and is commercially available.

Technology Cost

No available information.

T0859

VerTech Treatment Systems

Aqueous-Phase Oxidation

Abstract

VerTech developed an aqueous-phase oxidation technology to treat municipal wastewater and hazardous and toxic organic waste. The technology contains a reaction vessel that is suspended in a cement-encased, mile-deep well. At the bottom of the reactor, wastes are subjected to pressures of 1400 pounds per square inch (psi). This, along with the addition of heat and oxygen, oxidizes over 96% of organic materials to carbon dioxide, water, biodegradable organic acids, and a sterile, inert ash that can be used in fired brick construction. Once the exothermic oxidation process is underway, energy can be recovered from the reactions to generate electricity.

The VerTech technology was first marketed in North America by Air Products and Chemicals, Inc. The first commercial facility began operation in 1994. The technology is no longer available through Air Products and Chemical, Inc. All information provided is from the vendor and has not been independently verified.

Technology Cost

The Environmental Protection Agency (EPA) estimated the processing and operating costs at the Longmont Wastewater Treatment Facility, in 1984 and 1985, to be $100 per dry metric ton treated (D15571P, pp. 65–66).

The Veluwe Water Board paid a tipping fee of 595 Dutch Guilders per metric ton of sludge ($276/U.S. dry ton), which included sludge processing and operating, liquid effluent treatment, capital recovery, and solids residual removal costs (D15571P, p. 66).

Information Source

D15571P, Bowers et al., 1991

T0860

Viatec Recovery Systems, Inc.

Waste Acid Detoxification and Reclamation

Abstract

Viatec Recovery Systems, Inc., has developed the waste acid detoxification and reclamation (WADR™) system for recovering metal-bearing spent acids, including sulfuric, hydrochloric, nitric, and hydrofluoric acids and their mixtures. The WADR system uses vacuum distillation and crystallization technology to transform the waste acid into three streams: a concentrated acid solution, water, and metal salts. The technology is commercially available and is in use for treatment of process wastes.

The vendor claims the following advantages for the WADR system:

- No chemicals are added, and no dilutions are necessary.
- Disposal costs are reduced, and there is the potential for waste elimination if the recovered metals can be reclaimed.
- The recovered acid can be reused, lowering purchase costs.
- The process can operate using excess or waste heat (i.e., low-pressure steam) as the energy source.
- The process accommodates a wide variety of acids and can be tailored to meet the requirements of small and medium size companies.

All information in this summary was supplied by the vendor and has not been independently verified.

Technology Cost

The vendor claims that since up to 90% of the spent acid can be recovered for reuse, that from \$0.75 to \$5.00/gal of spent acid can be saved in disposal and purchase costs. Because of these savings, the system can pay for itself in 12 to 18 months (D15502C, p. 2).

Information Source

D15502C, Viatec Recovery Systems, date unknown, vendor literature

T0861

Viking Industries, Inc.

Acidification–Volatilization and Recovery (AVR)

Abstract

The acidification–volatilization and recovery (AVR) technology is an above-ground process that treats cyanide waste. The technology treats soil (ex situ), nonmunicipal sludge waste, and can potentially treat groundwater (in situ).

The AVR technology has been used in the electroplating industry and can potentially be used in battery recycling/disposal, metal ore mining and smelting, and semiconductor manufacturing. The technology has treated the following cyanide-complexed metals:

- Nickel chloride: $NiCl_2$
- Ferrous nitrite: $Fe(NO_3)_3$
- Cadmium sulfate: $CdSO_4$
- Copper sulfate: $CuSO_4$
- Zinc sulfate: ZnSO4
- Mixtures of all F008, F009, F010, F011, F012 wastes

According to the technology developer, the AVR system can only be used on sludge that contains cyanide. Viking Industries no longer offers remediation technologies, and this technology is not commercially available.

Technology Cost
According to the technology developer, the following factors affect the cost of the technology, although no specific cost information is available (D15628P, p. 14):

- Utility/fuel rates
- Amount of debris in waste
- Labor rates
- Waste handling/preprocessing
- Initial contaminant concentration

Information Source

D15628P, VISITT 5.0

T0862

Vortec Corporation

Cyclone Melting System (CMS)

Abstract
The Cyclone Melting System (CMS^{TM}) is an ex situ thermal treatment technology for contaminated soils, sludge, sediments, and mill tailings. The system uses heat to oxidize organic contaminants and vitrify inorganic, radioactive, and heavy-metal contaminants. The influent wastes flow through the precombustor, the counterrotating vortex (CRV) in-flight suspension preheater, the cyclone melter, and the separator/reservoir. The product off-gases enter the vapor treatment system, and the effluent glassly product flows into a quench tank.

The technology has been demonstrated in pilot- and full-scale applications. The CMS technology is offered commercially through the vendor. Licenses are also available.

Vortec claims the following advantages using CMS technology:

- Processes solid wastes contaminated with both organic and heavy-metal contaminants.
- Uses various fuels including gas, oil, coal, and waste.
- Handles waste quantities ranging from 5 tons per day to over 400 tons per day.
- Recycles the particulate residue collected by pollution control system into the final glass product.
- Produces a vitrified product that meets U.S. Environmental Protection Agency (EPA) toxicity characteristic leaching procedure (TCLP) criteria for disposal.

Influent particle sizes must be less than 600 μm in diameter. Additives are required for the effective vitrification of some wastes. The quality of the produced glass product depends on the distribution of glass formers and fluxes in the feed material.

Technology Cost
In 1999, the Federal Energy Technology Center (FETC) stated that CMS technology achieves significant cost savings relative to existing joule-melting and plasma-heating processes. This was based on preliminary cost comparisons (D205301, p. 17). The vendor states that process costs for the cyclone melting system (CMS) would average from $40 to $250 per ton of waste treated

(D22958X, p. 6). If the influent wastes are contaminated with radionuclides or polychlorinated biphenyls (PCBs), processing costs would increase (D17204D, p. 6).

In 1997, the vendor stated that the costs of processing mixed Resource Conservation and Recovery Act (RCRA)/low-level wastes and Toxic Substances Control Act (TSCA)/low-level wastes were projected between $50 and $100 per barrel for drummed waste and between $100 and $200 per ton for bulk wastes. The theoretical wastes contained 30% moisture and consisted mainly of contaminated soils and mud (D17472V, p. 2).

Most of the available cost data for vitrification technologies are estimates based on pilot-scale operations. Such data are suspect because they are based more on extrapolation than on experience. These estimates are difficult to compare because the assumptions on which they are based may vary widely (D18248T, p. 55).

Many site-specific characteristics have an impact on vitrification technologies. One critical aspect of any thermal technology is the water content of the waste. Water dilutes feed material, requires energy to drive off, and physically limits the feed rate of waste. Feed preparation is another variable, which differs with the technology and with site-specific characteristics. Many estimates do not take into account site preparation and waste disposal costs. Only complete treatment life-cycle assessments can provide reliable comparison data, and such studies are, by definition, highly site and waste specific (D18248T, p. 55).

Factors that impact the costs associated with CMS technology include (in descending order of importance):

- Quantity of wastes
- Waste handling/preprocessing
- Amount of debris associated with waste
- Moisture content of soil
- Characteristics of soil
- Site preparation
- Initial contaminant concentration
- Labor rates
- Target contaminant concentrations
- Utility/fuel rates
- Characteristics of residual waste (D13902G, p. 38).

According to the vendor, the pilot-scale CMS unit in Hamerville, Pennsylvania, treated 10,000 lb of municipal solid waste ash at a cost of less than $100 per ton (D13902G, pp. 15, 30).

A pilot-scale CMS unit was evaluated by the U.S. EPA's Superfund Innovative Technology Evaluation (SITE) Emerging Technology Program in 1994. During the demonstration, 5000 lb of soil contaminated with arsenic, lead cadmium, and chromium were processed (D17201A). The vendor stated that the treatment costs for the evaluation were $100 per ton (D13902G, pp. 15, 30).

Information Sources

D13902G, VISITT 5.0, 1996

D17204D, Hnat et al., 1996

D17472V, Hnat et al., 1997

D18248T, Sigmon and Skorska, 1998

D205301, Federal Energy Technology Center, 1999

D22958X, U.S. EPA Reachit, undated

T0863

W.E.S., Inc.

Microb-Sparging

Abstract

Microb-Sparging™ is an in situ technology for the bioremediation of groundwater containing organic contaminants. The technology uses indigenous and proprietary microbes that are acclimated to the contaminated groundwater in an above-ground reactor, cultured, and then re-injected to bioremediate the contaminant plume. Re-injection is done using air injection, which creates a convection and mixing zone and increases the subsurface level of dissolved oxygen—a condition that favors bacterial growth.

W.E.S., Inc., has a patent pending for Micro-Sparging and will decide whether to license or franchise the technology after a patent is issued.

The vendor claims that the addition of oxygen during air sparging enhances the aerobic microorganism growth, accelerating breakdown of contaminants in the aquifer.

Technology Cost

A project using Micro-Sparging to remediate an unspecified amount of groundwater contaminated with petroleum hydrocarbons was estimated by the vendor to cost under $100,000, including postremedial monitoring (D148850).

Information Source

D148850, Kings Communication Group, Inc., June 1995

T0864

Walker Process Equipment

EnviroDisc Rotating Biological Contactor

Abstract

The EnviroDisc™ is a rotating biological contactor (RBC) that uses biological processes to degrade organic and/or nitrogenous (ammonia-nitrogen) contaminants in aqueous waste streams. Treatment is achieved as the waste makes contact with the media, enabling fixed-film systems to acclimate biomass capable of degrading organic waste. RBCs can be used for air stripping and biological degradation of contaminants in wastewater or groundwater.

RBCs have been successful in the treatment of water contaminated with acetone, cyanide, ammonia, chlorinated compounds, and organic solvents. However, they are susceptible to many of the same constraints as any biological treatment. They are not effective at removing most inorganics or nonbiodegradable organics. Wastes containing high concentrations of heavy metals, certain pesticides, herbicides, or highly chlorinated organics may inhibit microbial activity, and limit performance.

The EnviroDisc is a fully developed, commercially used RBC.

Technology Cost

According to an estimate by the Environmental Protection Agency (EPA), a single RBC unit will cost from $80,000 to $85,000 to purchase and install. This estimate was not made for the EnviroDisc but rather for an RBC in general, with a surface area between 100,000 and 150,000 ft^2 (D15372K, p. 7).

According to the vendor, a Model F89 EnviroDisc (100,000 ft^2 standard density media) would cost about $59,000, not including a cover or field service, and a Model F89N (150,000 ft^2 of high-density media) would cost approximately $67,000 on the same basis.

Information Source

D15372K, U.S. EPA, 1992

T0865

Wasatch Environmental, Inc.

Density-Driven Convection (DDC)

Abstract
Density-driven convection (DDC) is an in situ remediation technology for removing petroleum hydrocarbons from soil and groundwater. The technology supplies oxygen to promote natural aerobic degradation processes and uses air stripping to remove volatile organics. DDC consists of a groundwater sparging system, a groundwater recirculation system, and a soil vapor extraction system. The technology can remove petroleum products including gasoline, diesel, and oil, as well as halogenated organic compounds, from a wide range of soil types. DDC is patented and commercially available through Wasatch Environmental, Inc.

According to the vendor, some advantages of the technology include the following:

- Does not produce hydraulic fracturing or promote significant lateral contaminant spreading.
- Is applicable to both fine- and coarse-grained soils; is readily modeled and designed for field applications.
- Creates both vertical and horizontal groundwater flow, allowing penetration of low-permeability horizontal layers.
- Can be used to distribute inorganic nutrients for biodegradation.
- Eliminates the need for surface water treatment; may eliminate the need for surface vapor treatment for aerobically biodegradable contaminants in permeable soils.
- Relatively inexpensive to implement, particularly for shallow groundwater depths; very low maintenance and operational cost due to few moving parts.

Density-driven convection is limited to contaminants that can be degraded by indigenous bacteria under aerobic conditions. System modifications are required for contaminants that are sufficiently volatile to be stripped by air sparging but are not aerobically biodegradable. The cost of implementing the technology increases with depth to groundwater. In-well vapor stripping systems like DDC may also be ineffective at sites with shallow aquifers. Longer remediation times or a greater number of sparging wells may be required in lower permeability formations. According to the vendor, scale buildup has occurred in DDC wells at sites containing hard water and moderate iron content; clearing the scaling requires periodic high-pressure water jetting. The remediation time for a site increases as hydraulic conductivity decreases.

Technology Cost
According to the vendor, the average total cost for the DDC remediation technology is less than $9.00/$ft^2$ of plume area (D12946O, p. 2). The vendor states that DDC can cost up to 50% less

TABLE 1 Capital and Annual Operating Costs of the Density-Driven Convection (DDC) Technology at the Amcor Precast Site in Ogden, Utah (1994 Dollars)

Capital Costs	
Drill and install wells	$16,000
Install groundwater and vapor extraction system	$40,300
Install groundwater sparging system	$25,750
Electrical connections	$4,050
Trenching, soil disposal, backfilling, asphalting	$26,800
Air compressor and control trailer	$26,800
Initial system startup and debugging	$3,000
Project management, construction oversight, regulatory reporting, and coordination	$10,000
Total capital cost	$156,950
Annual Operating Costs	
Maintenance labor and parts	$30,000
System monitoring and reporting	$30,000
Electricity	$2,750
Total annual operating cost	$62,750

Source: Adapted from D14099I.

than other air sparging technologies. One factor contributing to lower costs is the blowers used for DDC, which are typically less expensive than those used for other air sparging technologies (D22637J, p. 2).

A DDC system was used to remediate a site located in Ogden, Utah. The capital costs for the remediation project totaled $156,950. This figure included expenses associated with drilling/installing the wells and sparging system, startup, and project management. The annual operating costs totaled $62,750, including electricity, maintenance, and monitoring expenses (D14099I, p. 9). The specific capital and operating costs for this project are summarized in Table 1.

A pilot study of DDC for the remediation of pentachlorophenol (PCP) was conducted at a wood treatment site in Denver, Colorado, in 1996. Using DDC, PCP concentrations at the site were reduced by 43%. The total cost of this pilot demonstration was $80,000 (D188709, p. 30).

A DDC system for the remediation of fuel hydrocarbons was installed at a site in Park City, Utah, in 1995. The cost of this application was approximately $99,000 for equipment installation, including costs associated with the thermal catalytic oxidizer. Total operations and maintenance costs were $46,000 (D188709, p. 27).

A DDC system was used to treat petroleum hydrocarbons at Keesler Air Force Base in Biloxi, Mississippi. One DDC well and 1 soil vapor extraction (SVE) well were installed for the pilot study at the site, and 32 DDC wells and 6 SVE wells were installed for the full-scale application. Total costs were $360,000, including $100,000 for the pilot study (D22635H, p. 5).

Information Sources

D14099I, U.S. EPA, 1995

D12946O, VISITT 5.0, 1995

D188709, U.S. EPA, 1998

D22635H, U.S. EPA, undated

D22637J, Pennington, 2000

T0866

Washington Group International and Spetstamponazhgeologia Enterprises

Clay-Based Grouting Technique

Abstract

The clay-based grouting technique uses clay slurries as a base for grout solutions. These solutions are injected into bedrock fracture systems to inhibit or eliminate groundwater flow through these pathways. The clay slurries may also be used as a base for slurry wall construction.

This technology is commercially available.

According to the vendor, there are several advantages to the clay-based grouting technique:

- Is capable of eliminating flows of up to 4000 gal/ min.
- Requires little maintenance.
- Uses locally available clays to lower costs.
- Can be formulated to resist acidic and basic conditions.
- Remains plastic for years; resists damage due to earthquakes or other shocks.
- Uses clays that do not react with the environment.

The clay-based grouting technique is a barrier technology. Barriers are designed to contain contamination, not to treat it.

Technology Cost

No available information.

T0867

Waste Management, Inc.

DeChlor/KGME Process

Abstract

The Waste Management, Inc. (WMX), DeChlor/KGME process involves the ex situ dechlorination of liquid-phase halogenated compounds, particularly polychlorinated biphenyls (PCBs). KGME is the active species in a nucleophilic substitution reaction in which the chlorine atoms are replaced with fragments of the reagent.

Laboratory- and pilot-scale tests were conducted at the Re-Solve Superfund site in North Dartmouth, Massachusetts, during May and June, 1992. The technology is no longer commercially available, and Waste Management Inc., no longer supports or employs the technology.

Technology Cost

No available information.

T0868

Waste Management, Inc./OHM Remediation Services Corporation

X*TRAX Thermal Desorption

Abstract

The X*TRAX technology is an ex situ low-temperature thermal desorption technology that removes organic contaminants from soils, pond sludges, filter cakes, and other solid media. This technology is not an incinerator or a pyrolysis technology. Chemical oxidation and reactions are discouraged by maintaining an inert atmosphere and low treatment temperatures inside the unit. Combustion by-products are not formed because neither a flame nor combustion gases are present in the desorption chamber.

Contaminated feedstock is heated in an indirectly fired rotary dryer. The vapors are then transported to a gas treatment system via an inert gas such as nitrogen where they are scrubbed and cooled to condense the organics. The carrier gas is reheated and recycled to the dryer. The recovered organics can be reclaimed, used on-site or off-site as fuel, or incinerated. The technology is available in laboratory-, pilot-, and full-scale systems.

The X*TRAX technology was demonstrated in the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration program in May 1992. The X*TRAX technology is currently commercially available.

This technology has been used to treat polychlorinated biphenyls (PCBs), halogenated and nonhalogenated solvents, semivolatile organic compounds (SVOCs), polynuclear aromatic hydrocarbons (PAHs), pesticides, herbicides, fuel oils, benzene, toluene, ethylbenzene, and xylenes (BTEX), and mercury. This system has also treated Resource Conservation and Recovery Act (RCRA) hazardous wastes such as petroleum refinery wastes and multisource leachate treatment residues to meet RCRA Land Disposal Restrictions (LDR) treatment standards.

With the exception of mercury, the X*TRAX technology cannot remove nonvolatile metals or volatile metals from contaminated soils. However, chemical stabilization reagents can be added to the treated solids to reduce the leachability of heavy metals. The presence of tar or heavy pitch creates material handling problems. Soils rich in humic materials, such as topsoil, should be avoided. This technology is best suited to treat soils containing organics with boiling points less than 800°F and consisting of less than 10% total organics and less than 60% moisture.

Technology Cost

Treatment price is within the range of $150 to $250 per ton of feed based on a 1990 estimate. This cost is dependent on waste type, specific contaminants, and other project-specific variables including disposal requirements and restrictions and the amount of waste processed. This estimate is based on a lower treatment limit of approximately 5000 yd^3 of waste material. This limit was chosen to keep the mobilization charges to bring equipment on-site within reason (D12698R, p. 203).

The cost to treat 44,000 tons of contaminated soil and sediment at the Re-Solve Superfund site in North Dartmouth, Massachusetts, was approximately $6,800,000. This represents a unit cost of $155 per ton of soil treated. These costs include site preparation, mobilization, and demobilization of the unit, capital equipment, startup, labor, consumable materials, utilities, handling of residues and waste associated with the unit, transportation, disposal, maintenance, and modification (D19666B, p. 142).

Information Sources

D12698R, Swanstrom and Palmer, 1990

D19666B, U.S. EPA, 1998

T0869

Waste Microbes International, Inc. (WMI)

WMI-2000

Abstract

Waste Microbes International, Inc. (WMI) has a series of bacterial cultures designed to augment aerobic metabolism of petroleum products and other contaminants. The WMI-2000 is a blend of microbes for biodegradation of crude oil, chlorinated compounds, aliphatics, aromatics, pesticides, polynuclear aromatics, and esters. The technology is designed for the remediation of spills in soil, stormwater contaminants, groundwater contaminants, and in waste oil tanks. The technology may be used for in situ or ex situ treatment.

All information is from the vendor and has not been independently verified.

Technology Cost
No available information.

T0870

Waste Stream Technology, Inc.

Bioremediation

Abstract
The Waste Stream Technology, Inc. (WST), bioremediation technology uses microorganisms called WST Bioblends that are designed to remediate soil and water contaminated with organic compounds (bioaugmentation).

WST claims that the technology treats soil (in situ) and potentially treats natural sediment (in situ). The developer claims that WST Bioblends biodegrade benzene, ethylene, toluene, and xylene (BETX) volatile aromatic hydrocarbons.

According to the developer, the technology is applicable in the following industries: coal gasification, dry cleaning, industrial landfills, inorganic/organic pigments, machine shops, and plastics manufacturing.

Technology Cost
The developer's estimated cost for using the WST bioremediation technology ranges from \$25 to \$100/yd^3 of material. The following factors affect the unit cost of the technology (D103593, p. 22):

- Initial contaminant concentration
- Target contaminant concentration
- Moisture content of soil
- Depth of contamination
- Depth to groundwater
- Soil characteristics
- Waste quantity
- Residual waste characteristics
- Waste handling/preprocessing
- Site preparation
- Amount of debris with waste

Information Source

D103593, VISITT 4.0

T0871

WASTECH, Inc.

Solidification and Stabilization

Abstract
WASTECH, Inc., has developed a solidification and stabilization technology to produce a final waste form for soils, sludges, and liquid wastes. First, a proprietary reagent chemically bonds

with contaminants in wastes. The waste and reagent mixture is then combined with pozzolanic binders and Portland cement to form a stabilized matrix. Reagents are selected based on target waste characteristics. Treated material forms a nonleaching, high-strength, stabilized end product. The vendor claims WASTECH processing can deal with contaminant concentrations from the parts per million range to 40% by volume.

WASTECH processing does not destroy wastes; it is a stabilization technique. According to the vendor, results vary according to the contaminant treated.

Technology Cost
No available information.

T0872

Water and Slurry Purification Process (WASPP) Corporation

Alternating Current Electrolysis

Abstract
The Water and Slurry Purification Process (WASPP) Corporation developed an electrolysis technology for the ex situ treatment of heavy metals, acids, bases, and cyanides in sludges and slurries. The technology uses alternating current (AC) electrolysis to electrically separate heavy metals and cyanides from sludges and slurries that contain less than 20% suspended solids. According to the technology developer, the technology is patented.

The technology treats soil, nonmunicipal sludge, and natural sediment. According to the technology developer, the technology treats metals, acids, bases, and cyanides.

The developer claims that the technology is more successful on sludges or slurries containing less than 20% suspended solids.

The status of the commercial availability of this technology is unknown at this time (April 1997).

Technology Cost
According to the technology developer, operating costs for using the alternating current (AC) electrolysis technology vary, depending on the type of media. If using commercial power, the cost for using the technology to treat mining wastes would be approximately 60 cents per 1000 gal. If acids or bases are used to extract water from the mining wastes, the operating cost would be approximately 0.05 cents/gal of waste treated. The cost of the technology is affected by the strength of the molecular bonds within the molecules when treating complex molecules such as polychlorinated biphenyls (PCBs) and pesticides (D10318U, p. 2).

Information Source

D10318U, VISITT 4.0

T0873

Water Equipment Services, Inc. — Environmental Division

Vacu-Point

Abstract
Water Equipment Services, Inc.—Environmental Division (WES) developed the Vacu-Point™ technology, a new high-powered extraction process that, according to the developer, can remediate contaminated groundwater in an average of 90 days. The technology remediates sites

contaminated with organic compounds by extracting the contaminated groundwater and removing volatile organic compounds (VOCs) from the soil. The technology lowers the water table to expose highly contaminated soil to an ambient or induced airflow, allowing hydrocarbons to be stripped from the soil pores.

The technology has been applied primarily at sites contaminated with petroleum hydrocarbons. The Vacu-Point technology can remove hydrocarbons and chlorinated solvents from contaminated groundwater and soil. The developer asserts that the technology can treat VOCs, and all phases of non-aqueous-phase liquids (NAPLS) and dense non-aqueous-phase liquids (DNAPLS).

The developer asserts that the technology has the following advantages:

- Technology can retrace a plume that has migrated off-site even if access to adjoining property is not possible; applies a tremendous extraction force to both soil and water, allowing off-site migration to commonly be retracted back to the originating source.
- Reduces costs due to short remediation period of approximately 90 days.
- Facilitates airflow through the subsurface and thus enhances bioremediation.
- System controls surrounding water table, reducing off-site contaminant migration.

Technology Cost

According to the developer, the cost for using the Vacu-Point technology is $150,000 at an average site, compared with $90,000 for traditional pump-and-treat technologies at the same site. The developer claims that the technology costs more initially when compared to traditional pump-and-treat methods, but the overall operating expense is less because the technology requires a shorter remediation period (D148861, p. 1). The developer asserts that the Vacu-Point technology can usually complete a remediation in months in comparison to a traditional technology that takes years, requiring annual operating and maintenance costs of $40,000 (D13117Z, p. 16; D14891Y, p. 33).

According to the developer, a conventional technology could cost $300,000 to remediate a site over a 4-year period, while the Vacu-Point technology would cost less than $100,000 to remediate the same site over a 90-day period (D13109Z, p. 88).

Generally, capital outlay costs are lower because the modular, enclosed equipment is rented or leased during the remediation period at a fraction of the cost of a permanent plant (D13109Z, p. 88).

Information Sources

D14891Y, November 2, 1994

D148861, June 1995

D13109Z, Ground Water Monitor, June 1, 1995

D13117Z, 1995

T0874

Water Technology International Corporation

Self-Sealing/Self-Healing Barrier (SS/SH)

Abstract

Environment Canada licensed Water Technology International Corporation (WTIC) to develop and commercialize a patented self-sealing/self-healing (SS/SH) barrier system (jointly owned by the Netherlands Energy Research Foundation). According to WTIC, the most significant feature of the barrier is its ability to repair itself if it is breached.

The SS/SH barrier concept is based on the assumption that two reactive materials placed in layers will react at the interface to form an insoluble precipitate. The precipitate is designed to form a seamless, impermeable seal that will prevent the transmission of leachate and contaminants to the surrounding media.

WTIC claims that the SS/SH barrier is designed to be used as either a liner or cover for waste landfills, contaminated sites, secondary containment areas, etc. in the industrial, chemical, mining, and municipal sectors. WTIC claims that the SS/SH technology is also designed to be used as a barrier to hydraulic flow in the transportation and construction industries.

Technology Cost
No available information.

T0875

Waterloo Barrier, Inc.

Waterloo Barrier

Abstract
The Waterloo Barrier™ is a low-permeability cutoff wall for groundwater containment and control. The technology uses steel sheet piling with joints that can be sealed after the sheets have been driven into the ground. This technology has also been used as a soil-gas barrier.

The Waterloo Barrier has been available commercially since 1993. Slurry Systems, Inc., of Gary, Indiana, and The C3 Group of Breslau, Ontario, Canada, are licensed to install Waterloo Barrier. The technology is the subject of several patents held by the University of Waterloo and has been used at over 25 contaminated sites in North America.

According to the vendor, features and benefits of the Waterloo Barrier include:

- Rapid installation and sealing
- Minimal disturbance of site during construction
- Easy adaptation to irregular layouts
- Ease of inspection and monitoring for superior quality assurance and quality control during construction
- Predictable hydraulic performance
- Easy installation in areas with high water tables and surface water
- Service life in excess of 30 years for permanent installations
- Easy removal for temporary applications

The Waterloo Barrier does not remediate wastes. The contaminant plume must be small enough for enclosure to be practical. The vibration and noise associated with pile driving equipment may be a problem in densely populated areas. Funnel-and-gate system can be problematic because they alter groundwater flow. In bouldered terrain and very dense unconsolidated sediments, the use of sheet piling may not be possible. Steel sheet pile applications are generally restricted to depths of less than 30 m. At some sites it is necessary to seal the barrier system to bedrock.

Technology Cost
The cost of this technology is site specific and depends upon the size of the project, location, thickness of the sheet pile, depth of the installed barrier, soil conditions, and type of sealant. According to the vendor, prices generally range from \$15 to \$28/ft^2 of fully installed wall.

This cost estimate includes mobilization, materials, pile installation, joint flushing and sealing, labor, a quality assurance/quality control program, and a final report (D22932N, p. 18; personal communication with Waterloo Barrier, Inc., 1998).

A Waterloo Barrier was installed to a depth of 32 ft at Canadian Forces Base Borden in Ontario, Canada. The sheet piles interlocked to form a cell that was 18 ft long and 5 ft wide. The joints were sealed with a bentonite-base sealant. The barrier was used to control groundwater flow to allow for the installation of a permeable reactive barrier (PRB). After the PRB was installed, the Waterloo Barrier was removed and treatment began. The installation costs for the PRB were $30,000. This total included the installation and removal costs for the Waterloo Barrier but excluded the costs for labor and the reactive material used in the PRB (D21297F, p. 33).

At the Dover Air Force Base in Delaware, a Waterloo Barrier was emplaced as part of a funnel-and-gate system in 1998. The sheet piles extended to a depth of 45 ft and were keyed to a clay aquitard. The total costs for the funnel-and-gate PRB were $800,000. This figure included design, construction, materials, and the reactive media (D206097, p. 1).

Information Sources

Personal communication with Waterloo Barrier, Inc., 1998

D206097, Remediation Technologies Development Forum, undated

D21297F, U.S. EPA, 1999

D22932N, Waterloo Barrier, Inc., undated

T0876

WaterSmart Environmental, Inc.

Express Process

Abstract

WaterSmart Environmental, Inc. (WaterSmart), has developed the Express™ process technology for simultaneous treatment of contaminated soil and groundwater. Express, a combination of soil washing/leaching and in situ biological treatment, is an acronym for EXPedited REmediation Site Strategy.

The technology uses continuous flushing of contaminated soil with water from the aquifer that has been extracted and treated. Treated, nutrient- and oxygen-enhanced aquifer extract is recirculated to leach additional contaminants from the soil and the groundwater plume. Recirculation ensures steady biological reduction of contaminants. The Express process technology is currently commercially available from WaterSmart Environmental, Inc. All information contained herein has been provided by the vendor.

Technology Cost

No available information.

T0877

Weatherly, Inc./Chematur Engineering

Supercritical Water Oxidation

Abstract

Weatherly, Inc., developed the supercritical water oxidation (SCWO) system to treat liquid organic wastes. In February, 1999, Chematur Engineering acquired the exclusive rights to the

technology, which is marketed under the trade name of AQUA CRITOX®. This commercially available technology oxidizes organic compounds, with a destruction efficiency exceeding 99.9%, into benign products such as carbon dioxide and water.

In the SCWO process, water is subjected to temperatures and pressures above its critical point (374.2°C, 22.1 MPa), where it exhibits properties that differ from both liquid water and steam. At the critical point, the liquid and vapor phases of water have the same density. When the critical point is exceeded, hydrogen bonding between water molecules essentially stops. Supercritical water sustains combustion and oxidation reactions because it mixes well with oxygen and with nonpolar organic compounds. Some organic compounds that are normally insoluble in liquid water become completely soluble (miscible in all proportions) in supercritical water. Some water-soluble inorganic compounds, such as salts, become insoluble in supercritical water.

Weatherly, Inc., developed the first commercial SCWO system for Huntsman Corporation. The Huntsman facility in Austin, Texas, uses the SCWO technology to treat process and wastewater formerly disposed of by incineration. Weatherly, Inc., and the University of Texas at Austin have also studied the application of SCWO to contaminated soils, domestic wastes, mixed wastes, and military wastes.

The vendor claims advantages of the SCWO technology include the following:

- Process may be autogenic with the effluent generating sufficient heat to maintain operating conditions.
- Can operate as an enclosed system, including the capture of off-gases.
- Costs are competitive with incineration, cement kilns, and other destruction methods.

Limitations of the SCWO technology include the following:

- Stress cracking and salt plugging are often problems.
- Inorganic salts and oxides may have corrosive properties that can damage reactor vessels, heat exchangers, pressure letdown devices, and heaters.
- Low-organic-content waste streams may be more efficiently processed using other oxidation techniques or biological methods.
- Pretreatment is often necessary to obtain the proper percentage of organics and to render solids into a liquid or slurry form that can be pumped.

Technology Cost

Weatherly, Inc., estimated the cost of a full-scale commercial SCWO unit to be 10 to 20 cents per gallon (3 to 6 cents per liter) of waste treated. Cost estimates depend on the treatment capacity of the unit and the concentration of organic contaminants in the waste (D11868N, p. 3).

In 1995, Weatherly, Inc. estimated the cost of treating wastes at a small commercial SCWO facility to be 21.8 cents/gal (5.7 cents/liter). This estimate was based on the unit's operating 24 hr per day, 320 days per year, at a rate of 5 gal/min (19 liters/min), with an organic waste concentration of 1 g/liter. The cost estimate for a similar plant, treating a waste stream that contains 100 g/liter of organics, is estimated to be 23.3 cents/gal (6.1 cents/liter). Weatherly, Inc., estimated that a 30-gal/min (115-liter/min) facility could treat a waste stream with 1 g/liter of organics at a cost of 8.9 cents/gal (2.3 cents/liter). For an organics content of 100 g/liter, costs are estimated to be 10.3 cents/gal (2.7 cents/liter) (D11868N, p. 3).

For the Huntsman facility, the SCWO reactor was constructed in 14 months at a cost of approximately $2 million (D11868N, p. 1).

Information Source

D11868N, Stadig, 1995

T0878

Weiss Associates

Acoustically Enhanced Remediation

Abstract
Acoustically enhanced remediation (AER) is an in situ remediation technology that uses acoustic excitation fields (AEFs) to enhance rates of fluid and contaminant extraction from a wide variety of soil types. Bench-scale proof-of-concept tests have been completed and were followed by larger scale laboratory experiments. According to the vendor, a field-scale "proof-of-principle" step has been planned. The vendor indicates that this technology is currently commercially available; however, it is uncertain whether these field-scale tests have occurred.

According to the vendor, this technology has the following advantages and benefits:

- Treats hydrocarbons, chlorinated solvents, radionuclides, and metals in soils and bedrock (i.e., it is contaminant insensitive).
- Treats free-phase, dissolved, and sorbed contaminants (enhanced in situ).
- Augments existing remediation technologies such as groundwater pump-and-treat and soil vapor extraction.
- Augments advanced remediation technologies such as soil heating and steam flooding.
- Potentially reduces cleanup times and costs.

Acoustically enhanced remediation is designed to increase the time and yield of other technologies, not to directly treat contaminants.

Technology Cost
No available information.

T0879

Western Environmental Science and Technology (WEST)

Soil Washing of Lead-Contaminated Soil

Abstract
Western Environmental Science and Technology (WEST) had developed an ex situ soil washing technology designed for the treatment of lead-contaminated soil. This technology was particularly developed for use at shooting ranges.

WEST specializes in the development and application of soil washing technology for on-site remediation of contaminated soil. They have been remediating lead-contaminated soil since 1990. Their soil washing technology for lead-contaminated soils is commercially available.

Technology Cost
No available information.

T0880

Western Product Recovery Group, Inc.

Coordinate Chemical Bonding and Adsorption (CCBA) Process

Abstract
Western Product Recovery Group, Inc. (Western), has developed the coordinate chemical bonding and adsorption (CCBA) process for the ex situ treatment of soils, sediments, and sludges

contaminated with heavy metals. The technology forms the contaminated material with clay, forming pellets that are then heated, forming a vitrified ceramic product. The CCBA process has been demonstrated commercially on metal hydroxide sludges, and is commercially available.

The vendor claims that the CCBA process can be used on a variety of wastes, including sludges, sediments, and soils, contaminated with mixed organics and heavy-metal wastes. The process reduces the contaminated material to a nonleachable product composed of particles of sand to aggregate sizes. The treated wastes pass required leachability tests, and organic compounds are destroyed. The treated material can be disposed of on-site.

The CCBA technology cannot treat wastes that are composed of over 20% by weight organic material. All information included in this summary was supplied by the vendor and has not been independently verified.

Technology Cost

The vendors supplied a cost estimate for the VISITT 2.0 database. It was estimated that treating contaminated soil using the CCBA process would cost between \$150 and \$1000 per ton. This estimate stated that price estimates may not include all indirect costs associated with treatment, such as excavation, permits, and treatment of residuals. Factors listed as having a significant effect on costs include (in decreasing order of importance) the quantity of waste, clay costs, utility/fuel rates, waste handling and preprocessing costs, and labor rates (D157851, p. 7).

Information Source

D157851, U.S. Department of Energy, 1994, web page

T0881

Western Research Institute

Contained Recovery of Oily Wastes (CROW)

Abstract

The Contained Recovery of Oily Wastes (CROW™) process is a commercially available, in situ technology used to remove oily wastes from saturated and unsaturated soil. The technology uses steam and hot-water displacement to move accumulated oily wastes to production wells for above-ground treatment. According to the technology developer, CROW can be used to displace both light and dense non-aqueous-phase liquids (LNAPLs and DNAPLs) including pentachlorophenol (PCP) solutions, chlorinated solvents, creosote, and petroleum by-products.

The developer claims that CROW has the following advantages:

- It is cheaper than containment or excavation; in some cases, the recovered organic contaminant may be recycled, off-setting part of the processing costs.
- Technology performance is not limited by depth.
- Personnel have minimal exposure to contaminants because the system operates in situ.
- The process is faster than competing technologies.
- The technology can be used at sites with occupied buildings.
- The process requires no specialized equipment.

CROW does not substantially reduce contaminant levels in soils that do not contain free product. High levels of dissolved metals like iron can form suspended solids or promote bacteria growth that will foul the system by blocking injection wells and clogging machinery. Soil type, stratigraphy, contaminant characteristics/concentrations, and local hydrogeology/geology will influence the effectiveness of the CROW system. For example, low soil permeability and high soil heterogeneity may inhibit the process.

Technology Cost

The cost of applying CROW technology is largely dependent on site characteristics, site size, and the extent of process monitoring that is required. According to the vendor, the larger the site, the lower the cost per cubic yard of contaminated soil. For example, one 2.6-acre site had a projected cost of $\$30/yd^3$, while a 0.2-acre site had a projected cost of $\$250/yd^3$ (D14389P). The U.S. Environmental Protection Agency (EPA) puts these costs at $34 and $\$350/yd^3$, respectively (D213343, p. 68). Both sites had a 20- to 30-ft-thick contaminated zone within a highly permeable aquifer (D14389P). In 1995, CROW technology was anticipated to cost from $50 to $\$125/yd^3$ of soil treated (D12467E, p. 72).

The use of the CROW technology at the Brodhead Superfund site in Stroudsburg, Pennsylvania, cost at least $1.3 million less than the projected cost of excavation and disposal. In 1990, the estimated price of excavation and disposal was $3.3 to $6.8 million, depending on the ultimate disposal of the excavated material (landfilling or incineration) (D14391J). The total cost of the project was $1,900,000. The portion of total cost that was directly associated with treatment was $1,283,000. Pretreatment costs were $52,000, and demobilization costs were $80,000 (D18516U, pp. 273–275). See Table 1 for a breakdown of treatment costs. Additional cost data for the project is presented in D213343.

TABLE 1 Treatment Costs at the Brodhead Creek Site, Stroudsburg, Pennsylvania

Cost Elements	Cost ($)
Solids Preparation and Handling	
Residuals and waste handling and transporting	3,000
Startup Testing and Permits	
Permitting and regulatory	25,000
Startup	40,000
Operation	
Labor	150,000
Supplies and consumables	200,000
Utilities	40,000
Equipment repair and replacement	50,000
Engineering support	30,000
Instrumentation	25,000
Laboratory	50,000
Subcontractors	70,000
Travel and living expenses	70,000
Project management	50,000
Regulatory reporting and coordination	10,000
Miscellaneous/health and safety	10,000
Performance evaluation	10,000
Treatment verification	10,000
Remedial construction	400,000
Cost of Ownership	
Capital equipment	40,000
Total	1,283,000

Source: Adapted from D18516U.

Treatment costs using CROW at the Bell Lumber and Pole Company (Bell Pole) site in New Brighton, Minnesota, were calculated to be approximately $61,900 per pore volume. In comparison, costs for implementing CROW at the Brodhead Superfund site were calculated to be $85,000 per pore volume. According to the EPA, the Bell Pole project was cheaper because the aquifer at the site contained less dissolved iron and was more homogeneous (D213343, p. iv).

CROW was considered as a treatment option at the Koppers Industries, Inc., site in Oroville, California. The proposed treatment area consisted of four acres that were contaminated with creosote, pentachlorophenol (PCP), and polynuclear aromatic hydrocarbons (PAHs). For a 20-year treatment period using CROW, total present worth cost was predicted to be $26.8 million (D22673N, p. 48).

Information Sources

D12467E, Udell and Sitar, 1995
D14389P, Johnson, 1996
D14391J, Villaume, 1996
D18516U, U.S. EPA, 1998
D213343, U.S. EPA, 2000
D22673N, U.S. EPA, 1999

T0882

Westinghouse Hanford Company

In Situ Gaseous Reduction System (IGRS)

Abstract
The in situ gaseous reduction system (IGRS) is a technology designed to treat hexavalent chromium [Cr(VI)] and other metal contaminants in soil and groundwater. A dilute gas mixture, typically hydrogen sulfide (H_2S) in air, is injected into the contaminated region. The result of the reduction reaction is the immobilization of trivalent chromium [Cr(III)], which reduces its toxicity and mobility within soil and groundwater.

Benefits of the technology include avoiding risks to public health and worker safety associated with excavation, surface treatment, transportation, and disposal; and gaseous reactants increase permeability of soils to gases thereby allowing gaseous mixtures to invade smaller soil pores to react with soil contaminants. All information has been supplied by the developer and has not been independently verified.

Laboratory bench-scale testing of the technology indicate that in situ treatment of chromate-contaminated soils through the injection of hydrogen sulfide gas mixtures may be a feasible and effective remediation approach. It is unknown whether the technology will successfully treat other metals. A plan to demonstrate the technology in the field has been implemented, however, demonstration activities are on hold due to lack of funding. The technology is not yet commercially available.

Technology Cost
Estimated costs for the field demonstration of the IGRS have been summarized in Table 1. Initial estimates will be revised as actual cost data becomes available. These estimates are primarily those costs associated with actual waste site remediation and do not include all of the project costs associated with development of the technology. It is assumed that the total remediation effort will require 2 years (D14727N, pp. 23, 25).

The cost analysis provides a basis for calculating unit treatment costs associated with the in situ gas treatment. The proposed area, to be treated in the field demonstration, is 30 ft in diameter and has a depth of 40 ft, corresponding to approximately 28,274 ft^3. Based on the total treatment cost of \$342,000, the unit treatment cost is \$327/yd^3 or \$217 per ton of soil. This cost is comparable to costs for in-drum stabilization/solidification of excavated soils (\$200/yd^3) but higher than in situ mixing (\$10 to \$20/yd^3) (D14727N, pp. 23–26).

According to the developer, the economics may improve at a larger scale since a portion of the initial engineering and capital costs will not reoccur, thus reducing the cost per unit of treatment. For example, the configuration associated with the field demonstration may have the potential to treat a site that is 100 ft in diameter with a depth to 40 ft. With the total treatment cost at remaining at \$342,000, the unit cost for treating a site volume of 11,636 yd^3 is reduced to \$29.39/yd^3 (D14727N, p. 26).

TABLE 1 Estimated Cost Analysis for In-Situ Treatment with Hydrogen Sulfide

Cost Element	Cost (1996 \$)
Capital costs	
Gas treatment system[a]	25,000
Well network[b]	37,500
System installation[c]	5,000
Indirect capital costs[d]	200,000
Total installed cost	267,500
Operating and maintenance (O & M) costs	
Basic operating costs[e]	50,000
Maintenance[f]	3,000
Electricity[g]	5,500
Chemical costs[h]	2,000
Total O & M costs	60,500
Waste disposal cost	
Scrubber waste[i]	14,000
Total cost	342,000

Source: D14727N, Thornton and Miller, 1996.

[a] Capital costs of gas treatment system include purchase cost of system components and fabrication costs.

[b] Total installation and decommissioning costs for well-field network.

[c] Includes transport of gas treatment system and auxiliary equipment to site and installation of piping and site monitoring equipment.

[d] Engineering and administrative services including design and treatability testing activities, permit and document preparation, project management support, and field sampling and characterization activities. Cost estimated on the basis of one full-time employee (FTE) for 2 years (1FTE = \$100K/year).

[e] One-half FTE for one year.

[f] 5% of total equipment costs.

[g] 20 hp for 3000 hr at \$0.12/kWh.

[h] 180 kg (400 lb) hydrogen sulfide and 5700 liters (1500 gal) of caustic scrubber solution (1 M sodium hydroxide).

[i] Disposal cost for 5700 liters (1500 gal) of spent caustic solution (200 ft^3 at \$70/ft^3).

Information Source

D14727N, Thornton and Miller, 1996

T0883

Westinghouse Savannah River Company

Countercurrent Decanting (CCD)

Abstract
Westinghouse Savannah River Company is investigating countercurrent decanting (CCD) for treatment of high-level radioactive waste (HLW) prior to vitrification. CCD is a solid washing technology that uses a series of clarifiers to wash sludge. In the clarifiers, the wash water flows in the opposite direction relative to the solids. The process concentrates the sludge in the final washing stage and produces a liquid stream containing a very low solids content.

Although CCD is currently commercially used in industry, its use for treatment of HLW is still in the development stage. Future testing of this technology will include feasibility of its application to HLW sludge processing, based upon settling rates of simulated sludges and process flowsheet calculations. If found favorable, the next phase would be to demonstrate the technology on a small scale using actual waste. A pilot-scale system could then be designed for testing with simulants followed by full-scale implementation using simulants to test the equipment prior to testing with actual waste.

Technology Cost
No available information.

T0884

Westinghouse Savannah River Company

In Situ Bioremediation of Chlorinated Solvents with Natural Gas

Abstract
The U.S. Department of Energy's Office of Technology Development has sponsored full-scale environmental restoration technology demonstrations since 1990. The Savannah River Site Integrated Demonstration focuses on the bioremediation of groundwater contaminated by chlorinated solvents. Several laboratories, including the Savannah River site, have demonstrated the ability of methanotrophic bacteria (i.e., those that oxidize methane) found in soil, sediment, and aqueous material, to completely degrade or mineralize chlorinated solvents.

The test at the Savannah River Site consisted of injecting natural gas mixed with air into the contaminated aquifer directly below the site via two horizontal wells. At one well, which was installed under the water table, a mixture of methane and air was injected into the contaminated zone. Air was then extracted from the second well, which was installed just above the water table.

Results of the test showed that trichloroethylene (TCE) and perchloroethylene (PCE) concentrations in the water declined by more than 90% to below 2 parts per billion (ppb). All of the wells showed significant decreases in contaminants in less than 1 month. In four of the five piezometers (specialized monitoring wells whose primary purpose is the measurement of hydraulic head), TCE and PCE concentrations declined from as high as 10,000 parts per million

TABLE 1 Costs for In Situ Bioremediation with Natural Gas Injection

Type of Cost	Cost	Cost/lb of VOC	Cost/kg of VOC
Site costs (setup)	$5,400	$0.32	$0.70
Equipment costs	$60,505	$3.57	$7.87
Labor costs	$161,030	$9.51	$20.97
Consumable costs	$127,363	$7.52	$16.58
Total site costs	$354,298	$20.92	$46.13

Source: Adapted from D123477, p. 30.

(ppm) to less than 5 ppm in less than 6 weeks. Los Alamos National Laboratory models suggest that 43% more TCE and PCE is removed by this technology than by in situ air stripping alone.

According to the Westinghouse Savannah River Company, in situ bioremediation with natural gas injection quickly degrades and removes contaminants, is cost effective, produces no harmful side effects, and may be applicable to benzene, toluene, and other biodegradable organics where cleanup levels of less than 10 ppm are required.

High concentrations of volatile organic compounds (VOCs) can be poisonous to bacteria. At sites with high concentrations, in situ air stripping should be used to reduce the VOC concentrations before attempting in situ bioremediation. Site evaluation should include as assessment of the levels of nutrients in the soil to determine whether an additional carbon source or oxidizing agent is needed.

Technology Cost

The vendor claims that the cost of natural gas injection bioremediation may be less than $21/lb ($46/kg) of waste treated, compared to as much as $38/lb ($84/kg) for other techniques (Table 1) (D118127, p. 1).

When the natural gas injection process is combined with in situ air sparging, cleanup is more efficient and cost effective, according to Los Alamos National Laboratory cost estimates (D123455, p. 950). When tested at the Savannah River Site (SRS), a natural gas injection/air sparging combination versus the baseline technology (groundwater pump-and-treat and soil vapor extraction) resulted in a 40% cost savings. The added cost of natural gas injection to air sparging proved to be only about 8% [as little as 900 lb (410 kg) of contaminant needs to be biodegraded to offset the additional cost of adding natural gas to an air sparging system] (D118127, p. 4).

The SRS demonstration showed when natural gas was added to air sparging, cleanup would normally take 10 years to reach acceptable levels (95%) using conventional systems could be achieved in about 4 years to undetectable levels. Such a difference would result in a $1.5 million savings over conventional treatment systems for just the SRS demonstration (D118127, p. 4).

Short-term costs for in situ bioremediation with natural gas injection are derived using actual short-term field tests to calculate a cost per pound of VOCs remediated. Costs are as follows:

- Duration: 384 days
- Pounds of VOCs removed during vacuum extraction: 12,096 (5485 kg)
- Annual removal rate (pounds of VOCs) 11,498 (5214 kg)
- Total destroyed, with 40% biological addition (pounds of VOCs) 16,934 (7680 kg) (D123477, p. 290)

Information Sources

D118127, Hazen, 1996

D123477, Saaty et al., 1994

T0885

Westinghouse Savannah River Company

In Situ Air Stripping

Abstract
This technology uses a pair of horizontal wells to combine air injection below the water table with vacuum extraction in the vadose. In situ air stripping can be used to remove volatile organic compounds (VOCs) from soil and groundwater. Horizontal wells allow access under surface structures and buildings. Storage tanks and lines that are often associated with industrial operations can be accessed without demolishing above-ground structures or installing a vertical drilling rig within the structure.

This technology is currently commercially available.

According to the developer, the technology has several advantages:

- Allows for treatment under structures.

TABLE 1 Breakdown of Costs from the 1995 Demonstration at the Savannah River Site

Expense	Cost ($)
Equipment	
Design and engineering	5,000
Mobile equipment	15,000
Well installation—injection well	93,323
Well Installation—extraction well	76,762
Air injection system	3,500
Air extraction system	5,000
Vapor air separator	2,750
Carbon adsorption unit	10,000
Duct heater	3,250
Water treatment unit	4,000
Monitoring equipment	17,000
Temporary storage	1,500
Portable generator	3,500
Fuel storage	1,500
Piping and installation	5,200
Electrical	6,240
Other	63,440
Total equipment costs	253,525
Site costs	5,000
Labor costs (annual)	62,620
Consumable costs (annual)	
Carbon recharge	101,688
Fuel oil—diesel	35,362
Lubricants	6,950
Deionized water	3,336
Chemical additives	6,950
Maintenance supplies	3,475
Total annual consumable costs	157,761

Source: From D188083.

- Destroys contaminants in place, reducing treatment costs.
- Reduces duration of the remediation process.

Successful air stripping requires good contact between the injected air and the contaminated soils. The optimum geologic setting has moderate to high, saturated soil permeability, a homogeneous saturated zone, and sufficient saturated thickness. Heterogeneities in the subsurface can cause preferential airflow pathways and reduce system effectiveness. Air sparging is most effective in homogeneous, coarse-grained soils with high permeabilities and least effective in thick clay layers with low permeabilities.

Technology Cost

The U.S. Department of Energy's (DOE's) Los Alamos National Laboratory (LANL) conducted a costs analysis of in situ air stripping technology based on data from a 1995 demonstration at the DOE's Savannah River Site (SRS) near Aiken, South Carolina. Capital costs were annualized over an estimated 10-year equipment life. Carbon adsorption was included for off-gas treatment. The total cost of the demonstration was $15.59/lb of VOC removed. Table 1 shows a more detailed breakdown of these costs (D15726Q; D188083).

In 1999, another demonstration of in situ air stripping was conducted at the Nonradioactive Waste Disposal Facility at the DOE's SRS. The total cost of this demonstration was approximately $1 million (D19270V).

Information Sources

D15726Q, http://www.nttc.edu/Catalog/Tech_Cat_chap5_12.html
D188083, U.S. DOE, 1995
D19270V, U.S. DOE, undated

T0886

Westinghouse Savannah River Company/EnviroMetal Technologies, Inc. (ETI)

GeoSiphon

Abstract

GeoSiphon is a passive groundwater treatment system that can be applied in situ or ex situ. The system is a modified pump-and-treat technology, which uses the difference in water table depth between a treatment cell and a downgradient discharge point to generate a vacuum. This vacuum accelerates the flow of contaminated groundwater in the aquifer and pulls the water through a reactive media. GeoSiphon may be used as a treatment technology to prevent the migration of contaminants or as a collection mechanism for leachate or methane gas at a landfill. According to the developer, GeoSiphon can treat groundwater contaminated with chlorinated volatile organic compounds (CVOCs), halogenated solvents, inorganics, radionuclides, or heavy metals.

GeoSiphon is a patented technology developed by the Westinghouse Savannah River Company. It has been demonstrated at several U.S. Department of Energy (DOE) sites including the Kansas City, Missouri, plant, Lawrence Livermore National Laboratory, and the Savannah River Site. GeoSiphon is commercially available through EnviroMetal Technologies Inc. (ETI).

According to the developer, GeoSiphon has the following advantages:

- Minimal operation and maintenance costs are involved.
- Installation is easy and causes less site disturbance than alternative technologies.
- The process treats sites more quickly than comparable technologies (e.g., pump and treat).

- It is applicable to a variety of contaminants.
- Several configuration options are available.

GeoSiphon has several potential limitations and will not be applicable at all sites. Groundwater at a site must demonstrate a difference in hydraulic head in order for the system to operate. In addition, fluctuations in the water table may inhibit the system's performance. The technology may not be applicable at sites with deep contamination and nonsurficial aquifers. When iron is used as the reactive media, performance may also be limited by factors such as pH and high nitrate levels in groundwater.

Technology Cost

According to the developer, GeoSiphon is capable of treating a contaminated area more quickly than alternative systems. This feature can potentially reduce remediation costs (D18900Y, p. 2). The developer also claims that operation and maintenance (O & M) costs for GeoSiphon are 50 to 90% less than pump-and-treat O & M costs. In addition, the developer states that installation costs are less than the expenses associated with other permeable reactive barrier systems (D224339, p. 2). Site-specific variables, such as fluctuations in the water table, may affect GeoSiphon costs (D18900Y, p. 2).

At the Savannah River Site, remediation costs using a GeoSiphon system were approximately \$1.20 per 1000 gal of groundwater treated. The total cost for phase I testing of the system was approximately \$119,115. This figure included \$26,400 for the iron used in the treatment cell, \$27,411 for additional construction materials, and \$65,344 for mobilization, labor, rentals, and other installation expenses (D189020, pp. 19, 21; D19762A, p. 21; D206257, p. 2).

Information Sources

D18900Y, U.S. DOE, 1999
D189020, Savannah River Site, 1997
D19762A, Nichols, 1998
D206257, U.S. EPA, undated
D224339, U.S. DOE, 1999

T0887

Westinghouse Savannah River Company

Transportable Vitrification System

Abstract

The transportable vitrification system (TVS) is a large-scale, fully integrated ex situ vitrification system that treats low-level and mixed wastes in the form of sludges, soils, incinerator ash, and many other waste streams. The unit is designed to be transportable and easily decontaminated. Slurried or dry feed is mixed with glass formers, and the glass product is continuously poured into steel containers that are cooled, stored, and eventually disposed in low-level radioactive burial facilities.

The successful production of a nonleachable glass waste form from mixed low-level waste allows land disposal of the waste at a lower cost than the baseline technology (cementation) if it were used to stabilize the waste. This savings is primarily due to the large waste volume reductions realized during vitrification. In addition, glass final waste forms have been shown to have decreased leachability and increased structural stability as compared to the baseline waste form.

This technology is currently commercially available.

Technology Cost

In May 1998, the U.S. Department of Energy (DOE) estimated that transportable vitrification system (TVS) life-cycle waste processing and disposal costs would range from \$8 to \$15/kg of waste, depending on feed rates, size of feed preparation equipment, and vitrified waste delisting potential. This was based on the performance of TVS used to vitrify wastes at the DOE's Oak Ridge East Tennessee Technology Park (D179479, p. ix).

For the purposes of this estimate, it was assumed that the TVS unit would operate 24 hr per day. It was also assumed that the costs of a \$1.6 million equipment upgrade would be spread out over a 10-year life cycle, and that the unit would be operating at a feed rate of 50 to 100 kg/hr (D179479, p. 4–22).

The capital costs of the TVS plant used during the DOE demonstration were estimated to be \$5 million. The original TVS purchase cost was \$3 million, but updates to the system were required based on the results of tests at Clemson University and Oak Ridge. The vendor stated that a new plant similar to the TVS used during the demonstration would cost approximately \$5 million (D179479, p. 4–15).

Transportation costs for moving the TVS to Oak Ridge were estimated to be \$20,000. Site preparation costs were estimated to be \$350,000. These costs included:

- Preparation of the pad area
- Installation of the substation
- Installation of the propane line and tank
- Installation of the water line to the pad (D179479, p. 4–15)

Erection and installation costs at Oak Ridge were approximately \$420,000. This was the cost to install the TVS on the pad area and connect the utilities (D179479, p. 4–15).

Information Source

D179479, Department of Energy, 1998

T0888

Wet Oxidation — General

Abstract

Wet oxidation, sometimes referred to as wet air oxidation (WAO), is an aqueous-phase oxidation of dissolved or suspended organic and inorganic substances at elevated temperatures and pressures. During treatment, the contaminated materials are mixed with a gaseous source of oxygen (usually air) at temperatures of 150 to 325°C and pressures ranging from 2069 to 20,690 kPa to promote process reactions and control evaporation. The technology treats a wide range of hazardous organics in industrial wastewater and sludge. It can also be used as pretreatment for hazardous liquids or for carbon regeneration and sludge oxidation.

A similar technology to wet oxidation is supercritical water oxidation (SCWO), which operates at temperatures and pressures above the critical point of water (374.2°C, 22.1 mPa). A general discussion of SCWO is included in the RIMS library/database (T0756), and it lists several vendor-specific SCWO technologies.

There are several wet oxidation technologies included in the RIMS library/database. These include ADTECHS Corporation Wet Oxidation (WetOx) Process (T0008), Delphi Research, Inc. DETOX^{SM} Process (T0200), Institute of Gas Technology SELPhOx (T0414), VerTech Treatment Systems Aqueous-Phase Oxidation (T0859), and Zimpro's Wet Air Oxidation (T0827). A related technology that operates at similar temperatures and pressures but uses pyrolysis reactions rather than oxidation reactions is EnerTech Environmental, Inc's SlurryCarb^{TM} Process (T0254).

According to a document prepared by the U.S. Department of Energy (DOE) in 1996, the advantages of wet oxidation are that the process is comparatively simple, uses common and inexpensive reagents, operates at relatively low temperatures and pressures, and is versatile enough to destroy a variety of organic contaminants and some inorganic compounds. Organic wastes can be almost completely destroyed, and mixed wastes (wastes containing both hazardous and radioactive components) have the potential to be downgraded to low-activity wastes.

Pretreatment of wastes to homogenize waste streams or dilute incoming waste streams may increase processing costs. Difficulties have been reported with solids handling in wet oxidation systems. In many systems, processing wastes containing chlorine, sulfur, or phosphorous generates acids that must be neutralized in the reactor to prevent corrosion. This forms salts that can plug the reactor and other process machinery. Even with neutralization steps, corrosion is a concern.

Technology Cost

The capital costs associated with wet oxidation depend on several factors such as capacity of the system, oxygen demand of the wastewater, the properties of the waste to be treated, and the materials of construction of the system. Operating costs of the system are a function of the capacity of the unit, and the external energy requirements. (D16657Y, p. 8.88).

Wet oxidation technologies that are summarized in the RIMS library/database include the ADTECHS Corporation Wet Oxidation (WetOx) Process (T0008), Delphi Research, Inc. DETOX^{SM} Process (T0200), Institute of Gas Technology SELPhOx (T0414), VerTech Treatment Systems Aqueous-Phase Oxidation (T0859), and Zimpro's Wet Air Oxidation (WAO) (T0827). There are cost summaries provided for the Delphi Research, Inc., Institute of Gas Technology, VerTech Treatment Systems, and Zimpro technologies. No information concerning cost was available for ADTECHS.

Information Source

D16657Y, Copa and Gitchel, 1988

T0889

White-Rot Fungus — General

Abstract

White-rot fungus (WRF) is a wood-degrading fungus that can be used in biological remediation of organic contaminants in soil, sediments, sludge, or water. WRF belongs to a family of wood-rotting fungi common all over North America. The fungi secrete enzymes that break down lignin in wood to carbon dioxide and water, but these enzymes are nondiscriminating and are capable of degrading a wide variety of other organic compounds, including many environmental contaminants.

Laboratory studies confirmed that WRF can break down a wide variety of organic contaminants, some of which have historically been difficult for biological remediation using bacteria for degradation.

This technology has been known for 20 years and while it is commercially available, there have been relatively few field-scale applications. The application of this technology has been complicated by factors that include the inability to meet cleanup goals, toxicity inhibition, competition from native bacterial populations, and chemical sorption of the contaminants. Vendor-specific technologies using white-rot fungus that are summarized in the RIMS database include Mycotech Corporation Fungal Remediation (T0542), the United States Department of Agriculture Forest Service—Forest Products Laboratory *Phanerochaete sordida* (T0840), and Intech One Eighty White-Rot Fungus (T0416).

Technology Cost

In 1994, the U.S. Department of Defense (DOD) estimated the costs for soil treatment using white-rot fungus at \$75 to \$300/yd^3 (D10863E, pp. 4–13, D122714). No information is available on what this price included.

Also in 1994, Aust and Glaser estimated the cost of inoculum was the most expensive component of the technology and estimated the cost of their inoculum at \$1.32/kg. Contaminated soils receive a 5 to 10% loading of inoculum at the beginning of treatment (D11776K, pp. 242, 246).

In 1995, the U.S. Environmental Protection Agency (EPA) prepared a cost estimate of white-rot fungus technology based on a Superfund Innovative Technology Evaluation (SITE) demonstration conducted with the U.S. Department of Agriculture Forest Service—Forest Products Laboratory. Costs were estimated to range from \$400 to \$500/yd^3 of soil treated (D169613, p. 6).

In the SITE evaluation, three possible cost scenarios were considered. They all assumed treatment of 2500 yd^3 of contaminated sludge from a wood-preserving site, requiring 2500 yd of clean fill to be added. The contaminated soil and clean fill would be mixed and homogenized to reduce contaminant concentrations to acceptable levels. The different scenarios considered were staging the soil in a 3.72-acre plot requiring 6 months of treatment, a 1.86-acre plot requiring two treatment cycles over a 2-year period, and a half-acre greenhouse requiring eight cycles of treatment over 4 years (D169613, p. 6).

It was found that using the two smaller plots with multiple treatment cycles offered the lowest cost alternative (approximately \$410/yd^3). Consumables and supplies (mostly the cost of the inoculum) was among the top three cost categories for all three cases considered (23 to 32% of total costs). High front-end costs for site preparation are associated with the technology. These costs are minimized by decreasing the size of the staging area. As the number of treatment cycles increase, labor costs become a more significant factor. It was determined that the cost of treatment could be reduced if the potency of the inoculum were improved or if a fungal strain less susceptible to contaminant hot spots and physical damage was used (D169613, p. 6).

Information Sources

D10863E, DOD, Federal Remediation Technology Roundtable, 1994

D122714, Mycotech Corporation, vendor information

D169613, U.S. EPA, 1995

D11776K, Lamar and Glaser, 1994

T0890

WIK Associates, Inc.

Bugs+Plus

Abstract

Bugs+Plus™ is a product that combines a nutrient source and microorganisms selected for their ability to degrade hydrocarbon contaminants in soil. It can be applied in situ or ex situ. Bugs+Plus is a registered trademark of WIK Biosystems, Inc. It is commercially available and has been used in multiple full-scale field applications.

The Bugs+Plus product consists of two basic components, a nutrient source and microbes cultured for their ability to digest oil and other petroleum derivatives. The nutrient source is provided to encourage rapid microbial growth, which will be accompanied by microbial degradation of the hydrocarbon contaminants in soil.

The microbes supplied with Bugs+Plus have a limited container shelf life and must be applied within 72 hr of receipt. All information was supplied by the vendor and has not been independently verified.

TABLE 1 Bugs+Plus Costs, Including Discounts for Bulk Purchases

Total Cubic Yard Treated	Base Price	Discount %	Adjusted Price	Savings	Cost per Cubic Yard
50	$165.00	0	$165.00	$0.00	$3.30
100	$330.00	10	$297.00	$33.00	$2.97
300	$990.00	15	$841.50	$148.50	$2.81
1,000	$3,300.00	20	$2,640.00	$660.00	$2.64
2,000	$6,600.00	25	$4,950.00	$1,650.00	$2.48
5,000	$16,500.00	30	$11,550.00	$4,950.00	$2.31
10,000	$33,000.00	40	$19,800.00	$13,200.00	$1.98

Source: D16559X, vendor information.

Technology Cost

Table 1 gives costs for the Bugs+Plus system, including discounts for bulk purchases.

Information Source

D16559X, vendor information

T0891

Williams Environmental

RamSorb-1 Biologically Active Absorbent

Abstract

RamSorb-1 is a biologically active absorbent designed to be used for either in situ or ex situ bioremediation of hydrocarbon-contaminated soils. It may also be used to soak up hydrocarbons at smaller ground spills. Made from cottonseed lint and enhanced with nutrients, RamSorb-1 contains naturally occurring bacteria within its cellulose structure. It absorbs and encapsulates hydrocarbons, preventing leaching and further migration, while providing a medium for bacterial growth and the aerobic biodegradation of a wide range of petroleum hydrocarbons, including gasoline, diesel fuel, and used oils.

The vendor claims that under normal conditions, a minimum of 40% hydrocarbon degradation should occur every 30 days. Under optimum conditions, an 80% reduction in hydrocarbons can be achieved within 30 days. Soil temperatures above 120°F or below 40°F for extended periods may slow the degradation process. Excessive levels of some heavy metals, chlorinated solvents, fungicides, and pesticides will also slow bacterial growth.

This product has been successfully used to bioremediate several sites and is currently commercially available from Williams Environmental. All information contained herein was provided by the vendor and has not been independently verified.

Technology Cost

The RamSorb-1 biologically active absorbent is available by the 5-gal bucket (20 lb), 30-lb bag, pallet of 50 bags, 60-lb barrel, or the 140-lb barrel. Prices vary from $0.70/lb when purchasing a pallet of 30-lb bags, to $1.70/lb for the 5-gal bucket (D17810T, p. 14). See Table 1 for a detailed price list.

A minimum of one bag (30 lb should be added per cubic yard of soil). When applied as a bioremediation technique for high levels of hydrocarbons (up to 450,000 ppm), the vendor

TABLE 1 RamSorb-1 Pricing List

Size	Quantity	Cost[a]
5-gal pail (20 lb)	One 48-Pail Pallet	$33.95 per pail
30-lb bags	One to 49	$25.00 per bag
30-lb bags	One 50-Bag Pallet	$21.00 per bag
60-lb barrel	One	$55.00 per barrel
140-lb barrel	One	$120.00 per barrel

Source: D17810T, p. 14
[a]Prices may be lower when purchasing in bulk.

recommends adding an amount of RamSorb-1 equal to one half the calculated amount of hydrocarbons to be remediated. For example, if a cubic yard of soil is calculated to contain 500 lb of hydrocarbons, then 250 lb of RamSorb-1 should be added (D17810T, p. 10).

The vendor claims that when used for small spill cleanup, RamSorb-1 is able to absorb 4 to 6 times its own weight in oil, at an absorption cost of about $0.79/gal. This cost does not include disposal (D17810T, p. 2).

Information Source

D17810T, Williams Environmental, date unknown

T0892

WRS Infrastructure & Environment, Inc.

Soil Washing Process

Abstract

The WRS soil washing process (WSWP) is a commercially available, ex situ technology for the treatment of soils and sludges contaminated with organics, heavy metals, radionuclides, and combinations of contaminants.

According to the vendor, the WSWP removes contaminants from soil. A majority of the inlet soil is cleaned and discharged with contamination levels below a specified limit. The extracted contaminants are concentrated in the remaining, smaller portion of the soil for disposal (D10361X, p. 1).

The vendor claims that WSWP has the following advantages:

- Designed specifically to use and recycle aqueous-based leachates.
- Has a broad experience base on full-scale operation.
- Proven effective in handling soils that are difficult to wash, such as clays.
- Has compact design, quick setup, and high capacity.
- Has proven and documented high efficiencies in removing organic contaminants.

All information is from the WRS Infrastructure & Environment, Inc., and has not been independently verified.

Technology Cost

The vendor-estimated cost of remediation using WSWP was $150 to $250 per ton of soil treated in 1995. Soil characteristics, quantity of waste, and target contaminant concentration were cited as having the most significant effect on price (D10361X, p. 25).

Remediation activities cost $200 per ton of soil at the uranium mine in Bruni, Texas, and $150 per ton at the wood-preserving facility in Onville, California (D10361X, pp. 10, 20).

Information Source

D10361X, VISITT, July 1995

T0893

WRS Infrastructure & Environment, Inc.

Thermal Desorption Unit

Abstract

The WRS Infrastructure & Environment, Inc. (WRS), thermal desorption unit (TDU) is an ex situ contaminant separation and concentration technology that primarily treats contaminated soil. The contaminant is vaporized from the soil, collected, condensed, and placed into drums for testing and final disposition.

In the process, the TDU heats contaminant molecules above their boiling points to desorb the contaminants into the vapor phase in an oxygen-deficient environment, thus preventing oxidization of the contaminants. The volatilized contaminants and the moisture from the soil are condensed and collected within the system. The process is then controlled by using infrared heating and an alloy belt feed system within the TDU.

The technology treats soil, nonmunicipal sludge, and natural sediment, and potentially treats solid slag. In January, 2000, the TDU was offered as an asset available for liquidation by National Industrial Services, Inc.

According to the developer, the TDU removes volatile organic compounds and volatile metals from soil. The technology is designed to treat material contaminated with polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), dioxins, and volatile heavy metals (mercury).

According to the developer, the WRS TDU differs from other systems in that it utilizes an off-gas collection system rather than an off-gas incineration system. The off-gas collection system eliminates problems associated with incomplete combustion.

The developer notes the following limitations for the technology:

- Feed material should not contain more than 5% volatile organic compounds (VOCs) by weight.
- Moisture content of inlet material should contain a moisture content ranging from 5 to 20% by weight. (A predrying unit can be used in cases where the moisture content of feed material exceeds 20%.)

Technology Cost

According to WRS, the treatment cost for thermal desorption, excluding any pretreatment, ranges from approximately $150 to $300 per ton. Costs are determined by the following factors:

- Volume of material to be treated
- Moisture content
- Material gradation
- Types of contaminants
- Contaminant concentrations
- Soil characteristics
- Utility/fuel rates (D15057C, p. 900; D10415U, p. 16)

At the Acme Solvent Reclaiming facility in Rockford, Illinois, the total remediation project cost $150,000. The remediation activities averaged $225 per ton of material removed (D10415U, pp. 9, 10).

Information Sources

D10415U, VISITT 4.0
D15057C, O'Brien and Rouleau, November 30 –December 1, 1993

T0894

Xerox Corporation

Two-Phase Extraction Process

Abstract
The two-phase extraction process is a removal technology designed particularly for use in low conductivity formations such as silts and clays that are impacted by volatile organic compounds (VOCs). This technology removes VOCs from groundwater and/or soils.

Two-phase extraction uses a vacuum source to remove contaminated groundwater and soil vapor from the subsurface. The vacuum is applied to an extraction tube within a water well to increase groundwater removal rates and to volatilize and extract VOCs. According to the vendor, vacuum lift of water is not a limiting factor in the application of the technology. Since a mixed vapor/liquid column is extracted from the well, the two-phase extraction technology allows a single piece of equipment (a vacuum source) to remove contaminants in both the liquid and vapor phases.

The two-phase extraction method was patented by Xerox Corporation. Xerox has granted licenses on the technology to several vendors, including Radian Corporation, Haley and Aldrich, and Hydro Group, Inc., who currently offer the technology.

A vendor of the technology lists the following advantages of two-phase extraction:

- Groundwater is extracted without the use of expensive downhole pumps, wiring, or controls.
- Groundwater flow rates are increased.
- The water table is depressed, allowing for increased VOC extraction potential.
- System is modular, skid-mounted, and easy to install.
- System has the potential to drastically reduce treatment costs by reducing the duration of treatment and thereby reducing resultant life-cycle costs.

During the Superfund Innovative Technology Evaluation (SITE) the performance of the technology was proven to be very dependent on the characteristics of the soil at the site. The system only works as designed at sites with low permeabilities (typically with groundwater yields of less than 10 liters/min). At higher yields, the system is not able to maintain a stable air/water interface and converts to a groundwater extraction system.

Technology Cost
In 1996, the Environmental Process Improvement Center (EPIC) estimated the remediation costs for a two-phase extraction process would range from $70 to $160/lb of VOCs removed. EPIC is an alliance between the U.S. Department of Defense's (DOD's) McClellan Air Force Base, the U.S. Environmental Protection Agency (EPA), and the California Environmental Protection Agency (Cal-EPA) (D21566H, pp. 1, 3).

Information Source

D21566H, EPIC, 1996

T0895

Xetex Corporation

XeChlor Process

Abstract
The XeChlor^{SM} process is a reductive dechlorination process for the treatment of a wide array of organic halides, including conversion of polychlorinated biphenyls (PCBs) into biphenyl or dioxins into simple dibenzofuran. The dechlorination catalyst is prepared in situ from titanocene dichloride; sodium borohydride is the reducing agent.

Princeton University was awarded U.S. Patent 5,608,135 for the XeChlor process. The university has licensed the technology to Xetex Corporation. The process has been tested successfully on the bench and pilot scales, and on different waste matrices. Further research and development is being performed as the process is currently entering the commercialization stage.

Treatment of PCBs in soil may require more sodium borohydride than required for pure PCBs due to residual water and reducible humic components that might be present and consume sodium borohydride.

Technology Cost
Treatment costs are estimated at $250 per ton of waste material (D16557V), though the vendor states that the price may vary depending on the waste type (personal communication: R. Tanenbaum, Xetex Corp., 9/97).

Information Source

D16557V, Environtech, April 1997

T0896

Yellowstone Environmental Science, Inc.

Biocat II

Abstract
The Biocat II^{TM} technology can be used to treat liquid or slurry hazardous waste streams or to treat contaminated groundwater. It will remove aromatic hydrocarbons including benzene, toluene, ethylbenzene, xylenes, phenols and cresols; halogenated hydrocarbons including tetrachloroethylene, trichloroethylene, 1,1,1-trichloroethane, and similar xenobiotics; copper, lead, zinc, mercury, cadmium, and chromium metals; sulfuric acid, nitric acid, sulfate, and nitrate (D15639S, p. 5). The technology involves biotransforming halogenated hydrocarbons through the use of natural methanogenic bacteria, *Methanosarcina barkeri* strain 227 and/or *Methanosarcina vaculolata* (D13394I, p. 1).

The vendor claims several advantages including:

- Natural pH control and immobilization of metals to protect the enriched population of methanogens

- Conversion of the breakdown products of the toxic organics to methane that can be collected and used to heat water injected into a contaminated groundwater zone to thermally enhance biotransformations
- Elimination of releases of toxic volatile organic compounds to the environment that can occur with pump-and-treat-aerobic processes (D103640, p. 2)

The Biocat II technology is an improvement of the Biocat process (U.S. Patent 5,076,927), which treats acid mine drainage and heap leach effluents. The improvements were made under a Phase I Small Business Innovation Research (SBIR) grant funded by the Defense Advanced Research Projects Agency, a component of the U.S. Department of Defense (D10362Y, p. 4). If adequate concentrations of sulfuric acid are not present, additional acid may be required to operate the process.

Technology Cost
No available information.

T0897

Yellowstone Environmental Science, Inc. (YES)

Biocat

Abstract
Biocat™ is an ex situ technology that removes organic and inorganic contaminants from soil and surface waters, particularly acid mine drainage. The vendor claims that the advantage of this technology over prior acid mine drainage bioprocessing technologies is that the acid phase anaerobic digestion of the biomass is used to supply electron donors and carbon sources to the microbial sulfate reduction step of the process. This produces a stabilized sludge that is metal free that can be used as a soil conditioner in mined land reclamation efforts. The full-scale system is used in either batch, continuous, or semicontinuous mode. The technology is patented and commercially available.

According to the vendor, advantages of the Biocat system include:

- Does not use a large quantity of chemicals or energy to treat waste streams containing both acids and metals.
- Produces a waste product that is free of metals and may be used as a soil conditioner.
- Uses organic wastes to fuel the bioremediation process (D10363Z, p. 2).

Biocat is designed to operate in environments containing sulfuric acid. If adequate concentrations of sulfuric acid are not present, additional acid may be required to operate the process.

Technology Cost
No available information.

T0898

Zapit Technology, Inc.

Zapit Processing Unit

Abstract
Zapit Technology, Inc., developed the Zapit processing unit (ZPU), which uses electron beams to destroy vapor-phase toxic wastes. The ZPU has been developed to treat vapor-phase organic

wastes at temperatures of less than 400°F and at ambient pressures. Candidate waste streams include process off-gases and organics from soil vapor extraction or stripped from wastewater and groundwater streams. RIMS was unable to contact the vendor; therefore, the commercial availability of the technology is not clear.

For treatment by the ZPU, a waste stream must be in the vapor phase at near-ambient pressure, at a temperature of less than 400°F, and relatively free of particulate matter. Each compound in the waste stream has unique requirements for destruction. Many compounds are destroyed with a low application of energy, while others require a stronger application. The dose required for a specific combination of contaminants must be determined experimentally. Moisture may either enhance or reduce system effectiveness depending on the mixture. Compounds that act as free-radical scavengers or reducing agents may diminish the process efficiency. Concentrations of vapors that produce temperatures above 400°F in the reaction chamber through exothermic reaction must be diluted to keep the temperature below 400°F.

The ZPU is enclosed in a 4- by 9- by 6-ft steel frame and is considered self-contained and portable. It weighs about 2 tons and is designed to be moved with a fork lift and transported to sites by truck.

Technology Cost

The ZPU is expected to rent for around $250 per day (D15630J). The cost per pound of volatile organic compound treated is estimated at $2 to $20 (D10317T, p. 2).

Information Sources

D15630J, ET, December 1993

D10317T, VISITT 4.0, 1995

T0899

Zenon Environmental Systems, Inc.

ZenoGem

Abstract

ZenoGem™ is an ex situ system that combines bioremediation and microfiltration/ultrafiltration to treat contaminated groundwater, landfill leachate, industrial wastewater, and soil washing effluent. The technology is designed to remediate waste streams contaminated with high concentrations of volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) that cause elevated levels of biological oxygen demand (BOD) and chemical oxygen demand (COD). The technology uses aerobic biological treatment to remove biodegradable organic compounds. Membrane-based ultrafiltration is used to separate residual suspended solids from the treated effluent. The residual solids return to the bioreactor for further treatment and concentration.

The technology has been demonstrated in pilot-scale and full-scale applications to treat pharmaceutical effluent, oily wastewater, landfill leachate, tanneries effluent, contaminated groundwater, and food effluents. ZenoGem is patented and commercially available.

According to the vendor, the ZenoGem system has several advantages:

- Is less vulnerable to upsets or changes in hydraulic or organic loading.
- Improves effluent quality.
- Reduces sludge production.
- Destroys organic contaminants.

- Has a compact footprint.
- Is easily expandable.

The temperature can affect the performance of the ZenoGem system. Suspended solids can reduce the ZenoGem treatment efficiency. Elevated oil and grease concentrations may also limit the ZenoGem system's performance. The process is most efficient when the influent pH ranges

TABLE 1 Cost Estimates Based on the Superfund Innovative Technology Evaluation (SITE) Demonstration

Cost Category	Cost Item	Case 1 Costs ($)	Case 2 Costs ($)
Site preparation	Administrative	10,000	20,000
	Extraction and injection wells	4,000	NA[a]
	Building and concrete pad	NA	37,500
	Pump and piping	8,000	15,000
	Treatability study	5,000	7,500
	Design costs	2,500	18,900
	Total	29,500	98,900
Permitting and regulatory costs		5,000	12,900
Equipment costs	Treatment equipment	159,200	136,000
	Auxiliary equipment	NA	5,300
	Monitoring equipment	7,000	7,000
	Total	166,200	148,300
Mobilization and Startup costs	Treatment equipment	1,400	2,800
	Labor	2,800	3,900
	Utility connection	2,200	3,100
	Total	6,400	9,800
Site demobilization costs	Disassembly, decontamination, treatment equipment, and site restoration	5,100	1,700
Labor costs		12,700	17,100
Supply costs	Replacement membranes	NA	800
	Chemical additives	300	2,100
	Carbon columns	6,000	2,000
	Personal protection equipment (PPE)	200	200
	Sampling supplies	300	300
	Total	6,800	5,400
Utility costs	Electricity	7,400	28,000
Treatment and disposal	Effluent	NA	1,600
	Residual wastes	4,200	12,700
Analytical services costs		10,100	14,300
Equipment	Equipment	4,800	4,100
Maintenance costs	Labor	5,200	5,200
Total costs		263,400[b]	1,155,600[c]

Source: Adapted from D22728L.
[a]Not applicable.
[b]Total over a 1-year period.
[c]Total calculated for 10 years.

from 6.5 to 8.5. Insufficient quantities of nutrients in the bioreactor will decrease degradation rates. If oxygen levels in the bioreactor are low, oxygen may become a limiting factor.

Technology Cost

The U.S. Environmental Protection Agency (EPA) estimated the costs associated with two theoretical applications of the ZenoGem technology. These estimates were calculated based on the U.S. EPA's Superfund Innovative Technology Evaluation (SITE) demonstration of the technology, which was conducted in 1994 at the Nascolite Superfund site in Millville, New Jersey. In case 1, a rented, trailer-mounted ZenoGem system operated for 1 year. The system treated 1400 gal of contaminated groundwater per day. The theoretical system in case 2 was a skid-mounted system that treated 1400 gal of leachate per day. This system was purchased from the vendor and used for 10 years. In both cases, the influent was contaminated with methyl methacrylate (MMA), VOCs, and COD in concentrations similar to those experienced during the SITE demonstration. The total costs were estimated at \$0.50/gal of groundwater treated in case 1 and \$0.22/gal of leachate treated in case 2. The unit costs in case 1 are higher than the unit costs in case 2 due to the short remediation period (D22728L, pp. 1–3). Table 1 presents a breakdown of these cost estimates.

The actual costs associated with a ZenoGem application vary depending on the types of contaminants present at the site, contaminant concentrations, regulatory status and cleanup requirements, waste volume, site location and accessibility, hydraulic conductivity and saturated thickness of the aquifer, and groundwater chemistry (D22728L, pp. 39, 40).

Information Sources

D10506W, U.S. EPA, 1995
D10757D, U.S. EPA, 1995
D22728L, U.S. EPA, 1999

T0900

Zenon Environmental, Inc.

Cross-Flow Pervaporation System

Abstract

The cross-flow pervaporation system is an ex situ technology for the removal of volatile organic compounds (VOCs) from contaminated aqueous waste streams. Permeable hollow-fiber membranes preferentially adsorb VOCs. A vacuum on the other side of the membrane pulls the compounds through the membrane and partitions the VOCs from the aqueous stream. The organics may be recovered for reuse.

Pervaporation can be applied to groundwater, lagoons, leachate, rinse water, and industrial wastewaters contaminated with VOCs such as solvents, degreasers, and gasoline. The technology is applicable to the types of aqueous wastes currently treated by carbon adsorption, air stripping, and steam stripping. Cross-flow pervaporation systems are no longer commercially available from this vendor.

According to the vendor, the system has several advantages:

- Removal efficiencies are independent of VOC concentration.
- Costs are reduced by lack of chemicals, air, or sorbents.
- Recovered VOCs may be recycled.
- Breakthrough monitoring is not required.
- Volume of contaminated waste and disposal costs are reduced.

- System is transportable and compact.
- Process is automated.

In 1995, the U.S. Environmental Protection Agency (EPA) stated that the technology was not practical for reducing VOCs to most regulatory limits, notably drinking water standards. The technology was best suited for reducing high concentrations of VOCs to levels that can be reduced further and more economically by conventional treatment technologies.

The aqueous effluent may require further treatment or multiple passes through the system before discharge. Influent with high levels of alkalinity, calcium, or iron can cause scaling of the system. The technology does not treat highly soluble VOCs or inorganic compounds.

Technology Cost
According to the U.S. EPA, the treatment costs range from $2 to $4 per 1000 gal of influent. The costs of a remediation vary based on original and target contaminant concentrations, groundwater characteristics, the system's flow rate, and the volume of water to be treated. The costs increase slightly with contaminant concentration and are reduced by higher flow rates over time (D10507X, p. 3; D13677Q, p. 6).

Information Sources

D10507X, U.S. EPA, 1995
D13677Q, Canning, 1993

T0901

ZEROS USA, Inc.

Zero-Emission Energy Recycling Oxidation System

Abstract
The zero-emission energy recycling system (ZEROS) is a closed-loop thermal oxidation process that incinerates waste and recycles flue gas emissions for electrical co-generation. The technology uses a two-stage plasma torch combustion system, energy recovery system, and combustion gas cleanup systems.

According to the vendor, ZEROS can treat hydrocarbons and chlorinated compounds such as polychlorinated biphenyls (PCBs) and dioxins. The vendor claims that the technology can treat contaminated soils, liquid wastes in metal and plastic containers, asbestos, medical and biomedical wastes, contaminated sludges, waste fuels, fuel residues, and municipal solid waste. The technology is commercially available.

The vendor lists the following advantages of ZEROS:

- No "exhaust stack"
- No atmosphere/ozone impacts
- No "emergency stack opening"
- Low-cost electrical energy
- No "emissions"
- Air quality exemption achievable
- Increased system control
- Revenues from products

These claims and all information in this summary are from the vendor and have not been independently verified.

Technology Cost
No available information.

REFERENCES

T0001

CS: D14754Q, D17991D, D20305U, D20905C

TC: D20905C

GS: D12010L, D14754Q, D15640L, D17460R, D17476Z, D19252T, D20312T, D205618, D20904B, D20905C, D20955M, D20957O

TD: D112878, D12010L, D13964U, D14754Q, D14756S, D15640L, D15850T, D17460R, D17476Z, D17991D, D19252T, D19264X, D20116R, D20305U, D20312T, D205174, D20558D, D205618, D20678K, D20904B, D20905C, D20948N, D20949O, D20950H, D20951I, D20952J, D20953K, D20954L, D20955M, D20956N, D20957O

T0002

TC: D16170G

GS: D16170G

TD: D16170G, D16235G, D16236H

T0003

CS: D17645Y

TC: D179082

GS: D11886P, D17645Y, D177564, D179082, D19970G, D19972I, D19983L, D19984M, D19985N, D19986O, D19987P, D19988Q, D19989R, D19990K, D19991L, D19993N, D19995P

Complete bibliographic citations for these references can be found on the CDROM that accompanies the book. The following abbreviations are used throughout the references: **CS** = cost summaries; **TC** = technology costs; **GS** = general studies; **TD** = technology descriptions.

Wiley's Remediation Technologies Handbook: Major Contaminant Chemicals and Chemical Groups. By Jay H. Lehr
ISBN 0-471-45599-7

TD: D11886P, D13752K, D15344G, D15345H, D15346I, D17645Y, D177564, D179082, D19969N, D19971H, D19972I, D19973J, D19974K, D19975L, D19976M, D19977N, D19978O, D19979P, D19980I, D19981J, D19982K, D19984M, D19985N, D19986O, D19988Q, D19991L, D19992M, D19993N, D19994O

T0004

TC: D17112A, D17114C

GS: D13953R, D13954S, D167888, D167935, D17112A, D17114C, D17116E, D17117F, D17118G, D17119H

TD: D13953R, D13954S, D16140A, D167888, D167924, D167935, D16800N, D171119, D17112A, D17114C, D17115D, D17117F, D17118G, D17119H

T0005

CS: D140636, D140658, D14280D, D15417G, D198316, D198327, D222719

TC: D140636, D140658, D14280D, D177848, D177859, D19069W, D198327, D222719

GS: D140636, D140647, D140658, D14280D, D14629M, D15416F, D15418H, D177848, D177859, D17786A, D198258, D198305, D198316, D198327, D21305Y, D222708

TD: D10762A, D140636, D140647, D140658, D14280D, D14629M, D15416F, D15417G, D15418H, D177826, D177848, D177859, D17786A, D177906, D19069W, D198258, D198305, D198316, D198327, D19943D, D21305Y, D222708, D222719, D22272A

T0006

TD: D166896, D16690Z, D16741T

T0007

TD: D166885, D16690Z, D166910

T0008

TD: D166921, D18441S

T0009

CS: D14269I, D14270B

TC: D10009K

GS: D10009K, D14269I, D14272D, D14273E, D14274F, D14275G

TD: D10009K, D14269I, D14270B, D14271C

T0010

TC: D13970S

GS: D15661Q

TD: D13970S, D15661Q

T0011

GS: D16760W, D193742

TD: D167593, D16760W, D19371Z, D193720, D193742

T0012

TC: D14439I, D14800F, D208219, D22193C

GS: D106489, D14800F, D208219, D21022Q, D22193C

TD: D106489, D13457G, D13732G, D13736K, D142085, D14439I, D14800F, D15049C, D185584, D208219, D21022Q, D212373, D22191A, D22192B, D22193C, D22194D, D22195E, D22196F, D22197G, D22198H, D22199I, D22200U

T0013

TC: D10012F

GS: D10012F

TD: D10012F

T0014

TC: D10010D

GS: D10010D

TD: D10010D, D14396O, D16905V

T0015

CS: D12983T, D13887Y

TC: D20832C, D210480

GS: D10011E, D11600X, D12983T, D12984U, D13887Y, D13888Z, D20832C, D210480

TD: D10011E, D11600X, D12982S, D12983T, D12984U, D13887Y, D13888Z, D20831B, D20832C, D210480

T0016

CS: D20019R

TC: D20019R, D20023N, D22286G, D22287H, D22288I, D22289J

GS: D20019R, D22280A, D22282C

TD: D20019R, D20020K, D20021L, D20022M, D20023N, D20024O, D22280A, D22282C, D22286G, D22287H, D22288I, D22289J, D22290C, D22291D, D22292E, D22293F

T0017

TC: D10013G

GS: D10013G

TD: D10013G

T0018

TD: D161148, D161159

T0019

TC: D16271K

GS: D16271K

TD: D16271K

T0020

GS: D16649Y
TD: D16649Y, D16664X, D16665Y

T0021

TD: D16460N

T0022

TC: D14689Y, D14690R
GS: D14689Y, D18956E, D18957F
TD: D13034X, D13372C, D13373D, D13374E, D13527D, D13870P, D14682R, D14683S, D14688X, D14689Y, D14690R, D18154O, D18155P, D18956E, D18957F

T0023

GS: D14804J
TD: D14804J, D14805K, D14806L

T0024

CS: D141253, D141286, D16424J, D19057S, D19678F
TC: D141253, D141286, D15445K, D16424J, D19270V, D19320O, D19321P, D19673A, D19678F, D19683C, D19692D
GS: D141253, D141264, D141286, D141322, D15246F, D16424J, D185595, D19057S, D19270V, D19320O, D19321P, D19673A, D19678F, D19683C, D19692D
TD: D114294, D13935P, D13955T, D139940, D139951, D141253, D141286, D141322, D15246F, D15445K, D15842T, D158876, D16423I, D16424J, D16425K, D16427M, D16428N, D16493W, D185595, D19057S, D19270V, D19320O, D19321P, D19673A, D19678F, D19683C, D19692D

T0025

CS: D17255O, D18247S
TC: D18247S
GS: D17255O, D17256P, D17258R, D18247S, D203441, D203452, D221385, D221396, D22140Z
TD: D17254N, D17255O, D17256P, D17257Q, D17258R, D18247S, D203383, D203394, D20340X, D20341Y, D20342Z, D203430, D203441, D203452, D221363, D221374, D221385, D221396, D22140Z

T0026

TD: D15771V, D16335J

T0027

CS: D10758E, D13087A
GS: D10758E
TD: D10758E, D130869, D13087A

T0028

TC: D16458T, D16459U
GS: D16459U
TD: D16458T, D16459U

T0029

CS: D104654, D107335, D12487I
TC: D104654, D12487I
GS: D104654, D107335
TD: D104654, D107335, D12487I, D13920I, D16358Q, D16397X, D16995D

T0030

TD: D15617M, D15618N, D15619O, D15620H, D15621I, D18116I

T0031

TC: D13742I
TD: D13742I, D13743J

T0032

CS: D17789D
TC: D17789D
GS: D17789D, D186645
TD: D17704S, D17712S, D17713T, D17789D, D186645, D20600Y

T0033

TC: D16218F
GS: D16331F, D17127H, D17129J, D18887I
TD: D16218F, D16331F, D17124E, D17125F, D17126G, D17127H, D17128I, D17129J, D17130C, D18887I

T0034

TC: D11044R
TD: D105453, D11044R, D158901

T0035

CS: D12908I, D13940M, D15459Q
TC: D13940M
GS: D13940M, D15459Q
TD: D10685E, D12908I, D13791R, D13826L, D13940M, D14149B, D15459Q

T0036

TC: D22467J
GS: D16471Q
TD: D16471Q, D16475U, D16476V, D22466I

T0037

GS: D16471Q
TD: D16471Q, D16477W, D16478X, D212442, D22466I

T0038

TC: D19846D

GS: D16471Q, D16474T

TD: D11954K, D12379F, D16471Q, D16472R, D16474T, D17070H, D19846D, D198509, D212442, D21906H, D22466I, D22468K, D22469L

T0039

CS: D172009, D21034U

TC: D13550C, D13551D, D21034U, D221443, D221454, D221465

GS: D13550C, D13552E, D172009, D221443

TD: D11203O, D12488J, D132638, D132649, D13550C, D13551D, D13552E, D13553F, D172009, D18453W, D18454X, D21034U, D220393, D221294, D22130X, D221443, D221454, D221465

T0040

CS: D112903, D125188

TC: D112903, D125188

GS: D112903, D12385D, D124254, D125188

TD: D112903, D12385D, D12386E, D12387F, D124254, D124265, D124276, D124287, D124298, D125188

T0041

TD: D10017K

T0042

CS: D15632L

TC: D15632L

GS: D15632L

TD: D15632L, D157931, D15854X, D16146G

T0043

GS: D165871

TD: D14508E, D15718Q, D157920, D165871, D165882, D165893

T0044

CS: D177815

TC: D12674J, D20756H

GS: D12674J, D177815, D18283W, D19028N, D193844

TD: D10845C, D112721, D122190, D12222V, D12234Z, D12673I, D12674J, D133324, D14426D, D177815, D18240L, D18243O, D18278Z, D18283W, D19028N, D193844, D20746F, D20756H

T0045

CS: D18069S, D18070L

TC: D18070L, D22204Y, D222060

GS: D18066P, D18068R, D18070L, D22204Y
TD: D18066P, D18068R, D18069S, D18070L, D22204Y, D222060

T0046

TC: D10759F
TD: D10759F

T0047

TC: D16406H
TD: D16245I, D16407I

T0048

TC: D16406H
GS: D16404F
TD: D16245I, D16404F

T0049

TC: D16406H
TD: D16245I, D16405G

T0050

CS: D14173B
GS: D14173B, D14905N, D14906O, D14907P
TD: D14173B, D14905N, D14906O, D14907P, D14908Q, D152001

T0051

CS: D13779V, D13824J
GS: D13824J, D18024F
TD: D122678, D13618F, D13623C, D13779V, D13824J, D18024F

T0052

TC: D210571, D213376
GS: D15746U, D18614V, D18795F, D189075, D210571, D213376, D21926L, D21927M, D21928N
TD: D130472, D130483, D131646, D13792S, D14425C, D15746U, D18614V, D18795F, D189075, D210571, D213376, D21925K, D21927M, D21928N, D21929O, D21932J, D21933K

T0053

TC: D14167D
TD: D14166C, D14167D, D14191D

T0054

TC: D15569V, D185722, D18882D, D19033K, D20865L, D22185C, D22186D
GS: D13398M, D178625, D18328S, D185722, D19033K, D20865L, D22185C, D22188F
TD: D13398M, D15352G, D15569V, D178625, D178636, D18328S, D185722, D18603S, D18669A, D18891E, D19033K, D20577G, D20865L, D22185C, D22186D, D22187E, D22188F, D22189G, D221909

T0055

TC: D10018L
GS: D10018L
TD: D10018L

T0056

TC: D14265E
GS: D14265E
TD: D13196E, D14265E, D143088, D14721H

T0057

GS: D10019M
TD: D10019M

T0058

CS: D17454T, D17701P, D17702Q, D17703R, D18372W, D18978K, D19013G
TC: D17454T, D17702Q, D18978K, D19013G
GS: D17701P, D17702Q, D17703R, D19013G
TD: D17454T, D17701P, D17702Q, D17703R, D18372W, D18978K, D19013G

T0059

GS: D13213Y
TD: D13213Y, D14550G, D16441K

T0060

CS: D13753L
TC: D13753L
GS: D13665M, D13666N, D13667O, D13753L
TD: D13665M, D13666N, D13667O, D13753L, D14352C, D14468N, D18424R

T0061

TD: D131806, D13188E

T0062

TC: D177495
GS: D177451, D177473, D177484, D18892F
TD: D13187D, D132332, D13370A, D17123D, D177451, D177462, D177473, D177484, D177495, D17750Y, D177837, D18876F, D18892F, D18967H

T0063

GS: D14328C, D18442T, D18452V
TD: D14328C, D162049, D18442T, D18452V

T0064

GS: D14564M, D14566O, D14643K, D14644L, D14645M

TD: D13698V, D14564M, D14566O, D14643K, D14644L, D14645M, D14852R

T0065

GS: D11307V, D126307, D126329, D13718I, D18410L, D18412N

TD: D11307V, D126307, D126329, D12671G, D13295G, D13650F, D13718I, D14696X, D18410L, D18412N, D19963H, D19964I, D19965J

T0066

CS: D14684T

GS: D14639O, D14645M, D14684T, D150607, D15064B, D15065C, D15278N, D15279O, D15280H, D18436V

TD: D14639O, D14645M, D14684T, D150607, D15064B, D15065C, D15278N, D15279O, D15280H

T0067

TC: D10021G

GS: D10021G

TD: D10021G

T0068

CS: D15010X, D15010X

TD: D112914, D15010X

T0069

TC: D18642Z, D186441

GS: D18642Z, D186430

TD: D18642Z, D186430, D186441, D19771B, D203816, D203827

T0070

CS: D10008J, D10450X, D105624, D105646, D10586C, D10588E, D10589F, D10594C, D10864F, D111853, D120901, D120912, D122816, D14497S

TC: D10589F, D10864F

GS: D10008J, D10450X, D105613, D105635, D105646, D10588E, D10589F, D10864F, D120774, D12103P, D121562, D133120, D13419A, D19881G, D19882H, D19885K, D203816, D20738F, D20741A, D213332

TD: D10008J, D10450X, D105613, D105624, D105635, D105646, D10586C, D10588E, D10589F, D10594C, D10864F, D111853, D120774, D120901, D120912, D12102O, D12103P, D121562, D121675, D122816, D133120, D13419A, D14497S, D18721X, D18759B, D19881G, D19882H, D19883I, D19884J, D19885K, D203816, D20736D, D20737E, D20738F, D20739G, D207409, D20741A, D20742B, D20743C, D20775K, D20999Y, D213332, D213809, D21381A, D21382B, D21383C, D21384D, D21385E, D21386F

T0071

TC: D10324S, D18330M

GS: D10324S, D18330M
TD: D10324S, D13908M, D14281E, D18330M

T0072

CS: D10489C, D10790E, D147891, D14791V, D14793X, D152136, D17560U
TC: D14793X, D152136, D17560U
GS: D10489C, D14790U, D14791V, D14793X, D152136
TD: D10489C, D14674R, D147891, D14790U, D14791V, D14792W, D14793X, D152136, D17560U

T0073

TD: D16830T

T0074

TD: D16811Q

T0075

TC: D10023I
GS: D10023I
TD: D10023I

T0076

Case Study: D123331
TC: D123331, D136027
GS: D10025K, D123331, D136038
TD: D10025K, D10442X, D104803, D10686F, D10791F, D123331, D126249, D136027, D136038, D136049, D14175D, D21225Z

T0077

TC: D10024J
GS: D10024J
TD: D10024J

T0078

TD: D160203, D160214, D160225

T0079

TD: D16281M

T0080

TC: D13622B
GS: D11676H, D14477O, D163019
TD: D11676H, D11920A, D13622B, D13624D, D14477O, D163019, D17216H

T0081

GS: D16302A
TD: D16302A

T0082

TC: D14641I, D14642J
GS: D14641I
TD: D13470D, D14630F, D14641I, D14642J

T0083

TC: D167797
TD: D167797, D167800

T0084

CS: D11298B, D11299C, D116245, D116256
TC: D116256, D12104Q
GS: D11299C, D116234, D116245, D116256
TD: D11298B, D11299C, D116234, D116245, D116256, D116267, D120490, D12050T, D12104Q

T0085

TD: D109239, D11489G, D122521

T0086

TC: D14820J, D179424
GS: D14820J, D179424, D179435, D19578C, D19579D
TD: D14820J, D14821K, D14822L, D15414D, D179413, D179424, D179435, D19578C, D19579D

T0087

TC: D11866L, D14691S
GS: D14691S
TD: D11866L, D14691S, D18441S

T0088

CS: D12816F
TC: D10028N, D126034, D18248T
GS: D10028N, D12816F
TD: D10028N, D126023, D126034, D12816F, D12866P, D13956U, D18248T

T0089

TC: D10029O
GS: D10029O, D187342, D187353
TD: D10029O, D15529N, D187342, D187353

T0090

CS: D10030H, D140534, D140545
TC: D10030H
GS: D10030H, D140534, D140545, D17098T
TD: D10030H, D140512, D140523, D140534, D140545, D140556, D15101Z, D17099U

T0091

GS: D10031I
TD: D10031I

T0092

CS: D10033K, D10191X, D10192Y, D101984, D110930
TC: D10033K, D10192Y, D10869K
GS: D10191X, D10248X, D10868J, D110930, D17230F
TD: D10033K, D10191X, D10192Y, D101984, D10248X, D10271W, D10867I, D10868J, D10869K, D109206, D110930, D143226, D17230F

T0093

TC: D10036N, D15328G
GS: D10036N, D150618, D15328G, D19870D
TD: D10036N, D14703F, D14714I, D15058D, D150618, D15328G, D19870D

T0094

GS: D139882, D16059I
TD: D139882, D14599X, D16059I, D16060B

T0095

GS: D11856J, D11857K, D11859M
TD: D11748G, D11853G, D11856J, D11857K, D11859M, D13646J, D13647K

T0096

CS: D179388
TC: D15748W, D179388
GS: D15748W, D16422H, D179388, D179399
TD: D15748W, D16422H, D179388, D179399, D18403M

T0097

GS: D14599X, D14646N, D14647O
TD: D13302Y, D14596U, D14599X, D14646N, D14647O, D14673Q, D15090D

T0098

TC: D10066T
GS: D15672T
TD: D10066T, D10067U, D15672T

T0099

CS: D101995, D10251S, D10256X, D10257Y, D10257Y, D10261U, D102681, D10270V, D17023A, D17023A, D19855E, D205356

TC: D10256X, D11063U, D18600P, D19855E, D19859I, D19861C, D205356, D22273B

GS: D101995, D10251S, D10252T, D10256X, D10257Y, D10261U, D102681, D11063U, D11064V, D142438, D19312O, D19855E, D19859I, D19861C, D19868J

TD: D101995, D10251S, D10252T, D10256X, D10257Y, D10261U, D10264X, D10265Y, D102670, D102681, D102692, D10270V, D11033O, D11063U, D11064V, D11596I, D142438, D18600P, D19312O, D197277, D19855E, D19857G, D19858H, D19859I, D19860B, D19861C, D19863E, D19864F, D19865G, D19866H, D19867I, D19868J, D205356, D213376, D21495J, D21563E, D22273B, D22274C, D22275D, D22294G, D22295H

T0100

GS: D102670, D11062T

TD: D10251S, D102670, D11061S, D11062T, D11063U, D11064V

T0101

GS: D10062P, D15095I, D15096J

TD: D10062P, D15095I, D15096J

T0102

TC: D15330A

GS: D15330A

TD: D10042L, D10063Q, D10064R, D15330A

T0103

CS: D16706Q

TC: D16706Q

GS: D16706Q

TD: D16706Q

T0104

GS: D13747N

TD: D11144U, D13747N

T0105

TC: D13746M

GS: D133277, D13746M, D160156

TD: D11144U, D133277, D13746M, D13881S, D160156

T0106

TC: D170058

Complete bibliographic citations for these references can be found on the CDROM that accompanies the book. The following abbreviations are used throughout the references: **CS** = cost summaries; **TC** = technology costs; **GS** = general studies; **TD** = technology descriptions.

GS: D12979X, D14479Q
TD: D12947P, D12979X, D14479Q, D15744S, D170058

T0107

CS: D16055E, D16056F, D20214S, D20218W, D202675
TC: D16056F, D16057G
GS: D16056F, D16057G, D20214S, D20215T, D20216U, D20218W
TD: D16055E, D16056F, D16057G, D20214S, D20215T, D20216U, D20218W, D20289B

T0108

TC: D14900I, D17152I, D17154K, D17267S, D17268T, D21556F
GS: D148996, D17152I, D17153J, D17154K, D17266R, D17267S, D17268T, D21556F
TD: D13789X, D13948U, D148941, D148952, D148963, D148985, D148996, D167491, D17152I, D17153J, D17154K, D17266R, D17267S, D17268T, D21556F

T0109

TC: D16816V
TD: D16815U, D16816V, D16818X

T0110

Case Study: D14620D, D14621E, D14622F
GS: D14620D, D14621E, D14622F
TD: D14619K, D14620D, D14621E, D14622F, D18973F

T0111

GS: D189188
TD: D189177, D189188, D19702Y

T0112

CS: D10069W, D120865, D16052B, D16053C
TC: D10069W, D17224H
GS: D10069W
TD: D10069W, D112958, D112969, D11342Y, D11815A, D120865, D15247G, D16051A, D16052B, D16053C, D17224H, D183964, D18407Q, D18408R, D18409S, D18440R

T0113

CS: D120854, D14649Q
TC: D120854
GS: D14648P, D14649Q
TD: D120854, D14648P, D14649Q, D14850P

T0114

TC: D10044N

GS: D10044N
TD: D10044N, D15128A

T0115

TD: D144047, D144069, D160167

T0116

CS: D144003, D144014, D144036
TC: D14399R
GS: D144003, D144014, D144036, D14409C, D17218J, D17219K, D17220D
TD: D14398Q, D144014, D144025, D144036, D14407A, D14409C, D144105, D144116, D144127, D144138, D144149, D14415A, D14416B, D14417C, D14418D, D14419E, D17218J, D17219K, D17220D

T0117

CS: D122736, D170025
TC: D12052V, D12140U, D18685A
GS: D11964M, D11965N, D12052V, D122736, D170025
TD: D105668, D105679, D11964M, D11965N, D12052V, D12053W, D12135X, D12140U, D12218Z, D122736, D122747, D170025, D18685A

T0118

TD: D131759, D13913J, D14582O, D15241A, D16155H, D16156I, D16157J, D16158K, D16159L, D16522K, D18416R

T0119

GS: D15489W
TD: D11386A, D139860, D15405C, D15489W, D15579X, D15611G, D16069K

T0120

CS: D15139D, D151406
TC: D151406
GS: D14829S, D151304, D15139D, D151406, D182983
TD: D14829S, D151304, D151326, D15139D, D151406, D182972, D182983, D203587

T0121

TC: D151359
GS: D151337, D151348, D182983
TD: D151337, D151348, D151359, D182983

T0122

TD: D11203O, D13449G, D15263G

T0123

CS: D10692D, D12307Z, D12769P
TC: D12307Z, D12769P

GS: D12741D, D12769P

TD: D10692D, D12307Z, D12741D, D12769P, D12825G, D13769T, D13911H, D14089G

T0124

CS: D10460Z, D10693E, D110690

TC: D10460Z, D110690

GS: D10460Z, D12241Y

TD: D10460Z, D110690, D11819E, D12051U, D12241Y, D12854L, D135057, D158898

T0125

CS: D10498D, D118025, D11829G

TC: D10498D

GS: D10498D, D118025

TD: D10498D, D10776G, D118025, D11829G, D13807I, D13808J, D13809K, D13812F, D13813G, D13990W, D14001S, D143408

T0126

CS: D133084, D142030, D15147D, D151508

TC: D14011U, D14784W, D151508, D15156E, D19347Z

GS: D10191X, D10342U, D110930, D133084, D14496R, D14507D, D14509F, D145108, D145119, D14784W, D14949Z, D15066D, D15147D, D151508, D15152A, D15153B, D15157F, D15158G, D15160A, D15161B, D15162C, D15164E, D15165F, D15168I, D15544M, D17993F, D188709, D18949F, D195180, D196296

TD: D10007I, D10026L, D10081S, D10112I, D10117N, D10124M, D10305P, D103844, D10404R, D10859I, D11398E, D11669I, D117248, D11824B, D12031Q, D12774M, D133084, D139780, D14011U, D141399, D141548, D141719, D142030, D14294J, D14496R, D145108, D14580M, D14784W, D14785X, D15147D, D15148E, D151508, D15152A, D15155D, D15156E, D15157F, D15158G, D15160A, D15163D, D15165F, D15543L, D15544M, D15601E, D15834T, D15835U, D15844V, D160087, D19334U, D19399B, D195180, D196092, D19610V, D196296

T0127

CS: D125202, D213332

TC: D170036

GS: D125202, D12820B, D12894T, D12895U, D170036, D213332

TD: D112787, D125202, D12820B, D12894T, D12895U, D170036, D213332, D214277, D214299

T0128

TC: D14077C

GS: D14078D

TD: D12650B, D12846L, D14077C, D14079E, D140807

T0129

TC: D14819Q

GS: D14819Q

TD: D14818P, D14819Q

T0130

TC: D10048R, D14012V
GS: D14013W
TD: D10048R, D14012V, D14014X, D14948Y

T0131

CS: D10427Y, D10427Y, D10694F, D10697I, D12817G, D13031U, D13032V, D160010
TC: D10427Y, D11846H, D200953
GS: D10427Y, D10694F, D11242V, D200953, D203612
TD: D10427Y, D10694F, D11242V, D11846H, D12817G, D13032V, D13571H, D18234N, D197277, D200953, D203612

T0132

CS: D15187L, D15188M, D15192I
GS: D15187L, D15188M, D15190G, D176561
TD: D15178K, D15179L, D15180E, D15182G, D15183H, D15184I, D15185J, D15186K, D15187L, D15188M, D15189N, D15190G, D15191H, D15192I, D15193J, D15194K, D15482P, D15483Q, D176561

T0133

TC: D16621M
GS: D16622N
TD: D16621M, D16622N, D16623O

T0134

CS: D15076F, D15087I, D15087I, D15088J, D169737
TC: D15087I, D17262N, D21488K
GS: D15087I, D169737, D17262N
TD: D15087I, D15089K, D16221A, D169737, D17262N, D17263O, D19785H, D19786I, D19787J, D19795J, D21488K, D21489L

T0135

CS: D17122C
TC: D15749X
GS: D15749X, D17122C, D19361X
TD: D10224P, D10944E, D14920M, D15749X, D16099Q, D16580U, D17121B, D17122C, D18698F, D19361X, D20973O

T0136

TC: D12302U, D135159, D17097S, D197186, D197211, D197233, D22276E, D22279H, D22281B, D22285F
GS: D123626, D13102S, D135159, D17097S, D19424V, D197175, D197197, D197211, D197222, D197233, D213627, D22276E, D22279H, D22281B, D22285F
TD: D12302U, D123626, D130530, D13102S, D135159, D17097S, D19424V, D197175, D197186, D197197, D197211, D197222, D197233, D213627, D22276E, D22277F, D22278G, D22279H, D22280A, D22281B, D22282C, D22283D, D22284E, D22285F

T0137

TD: D14623G, D14624H, D14627K, D14628L, D14698Z

T0138

CS: D123262, D125359, D12783N

TC: D10057S, D123262, D125337, D125359, D12536A, D17231G, D17232H, D17233I, D19079Y

GS: D10057S, D123262, D123626, D125177, D125337, D125348, D125359, D12775N, D12783N, D15818T, D17231G, D187193, D19079Y, D197277, D20118T, D20119U

TD: D10057S, D104858, D107506, D112470, D113531, D123262, D123626, D125337, D125359, D12536A, D12775N, D15821O, D16420F, D17231G, D17232H, D17233I, D187193, D19079Y, D197200, D20118T

T0139

TC: D16658Z

GS: D16658Z

TD: D16658Z

T0140

CS: D16347N

TC: D187331, D188298, D189428

GS: D16347N, D16352K, D187331

TD: D11739F, D123160, D16341H, D16345L, D16346M, D16347N, D16349P, D16350I, D16352K, D187331, D188298, D18899M, D189428

T0141

CS: D15076F, D15087I, D15088J, D169737

TC: D15087I, D15088J

GS: D15087I, D15424F, D15497W

TD: D15073C, D15074D, D15075E, D15076F, D15081C, D15086H, D15087I, D15088J, D15089K, D15397T, D15423E, D15424F, D15497W, D169737

T0142

CS: D101871, D101871, D131384, D14732K

TC: D101871

GS: D101871

TD: D101871, D131384, D14732K, D14733L

T0143

GS: D101860

TD: D101860, D14397P

T0144

CS: D17603O, D17604P, D17606R, D17607S, D18030D, D18051I, D18055M, D18285Y, D182881, D18766A, D18766A, D18766A, D18766A, D19414T, D194461, D19781D, D19782E, D20940F

TC: D18055M, D18766A, D20940F, D22096C, D22102T, D22442A

GS: D18030D, D18051I, D18055M, D18766A, D19531X, D19782E, D201683, D20170X, D20171Y, D201752, D21459F, D21466E, D22030U, D22096C, D22097D, D22102T

TD: D123626, D133299, D18027I, D18028J, D18029K, D18030D, D18051I, D18052J, D18053K, D18054L, D18055M, D18056N, D18057O, D18058P, D18285Y, D18286Z, D182870, D182881, D182892, D18766A, D19414T, D19531X, D196525, D19781D, D19782E, D201672, D201683, D201694, D20170X, D20171Y, D20172Z, D201730, D201741, D201752, D20843F, D20940F, D210593, D21449D, D21459F, D21466E, D21918L, D21932J, D22030U, D22095B, D22096C, D22097D, D22098E, D22099F, D22100R, D22101S, D22102T, D22103U, D22442A

T0145

TC: D10185Z

GS: D10185Z

TD: D10185Z

T0146

GS: D14020V

TD: D13107X, D13734I, D13780O, D13782Q, D13882T, D13971T, D14020V, D14278J, D160101, D17743Z

T0147

TC: D16641Q

GS: D13803E, D15836V

TD: D11475A, D11476B, D11477C, D11478D, D123568, D157975, D16641Q, D16642R, D18441S

T0148

CS: D17269U, D17269U

TC: D17269U, D224099

GS: D17269U, D191940, D224099

TD: D17269U, D19192Y, D19193Z, D191940, D191951, D191962, D19212L, D19302M, D224099, D224102, D224248, D224259, D22426A

T0149

TC: D150141

GS: D16635S

TD: D13113V, D134021, D13766Q, D141184, D150141, D150196, D16633Q, D16634R, D16635S

T0150

TC: D16285Q, D16286R, D18214J, D19312O, D19867I

GS: D19312O, D19861C, D19866H, D19867I, D214368, D214379

TD: D16285Q, D16286R, D18214J, D19312O, D19857G, D19861C, D19866H, D19867I, D214368, D214379, D21438A

T0151

TC: D160429, D16044B

GS: D10273Y, D15720K, D16090H

TD: D10273Y, D15656T, D15712K, D15716O, D15720K, D158912, D160429, D16043A, D16044B, D16090H, D177451, D177473, D177484

T0152

CS: D10602V

TC: D11745D, D169522

GS: D10602V, D12198C

TD: D10211K, D10602V, D11745D, D11746E, D169522, D18441S, D18650Z, D186576

T0153

TD: D16835Y, D16836Z

T0154

CS: D10695G, D13120U, D132627

TC: D132627, D20539A

GS: D11679K, D13120U, D132627, D20549C

TD: D10695G, D11679K, D12369D, D12546C, D12709D, D127117, D12770I, D13120U, D132627, D13387J, D13760K, D13793T, D13794U, D158763, D158898, D197277, D19868J, D19934C, D19943D, D201865, D20539A, D20549C

T0155

TC: D14187H, D151100

TD: D104494, D130847, D151100, D151122, D151133

T0156

CS: D17718Y

GS: D17718Y, D17719Z

TD: D17718Y, D17719Z, D17720S, D17721T, D17722U, D17723V

T0157

CS: D16450L, D16452N

GS: D16450L, D16452N

TD: D16450L, D16452N

T0158

CS: D19710Y, D19710Y, D19711Z, D197120, D197131, D197437, D19747B, D19749D, D19749D, D198156, D198156

TC: D197120, D197131, D197437, D198156, D20756H

GS: D19749D, D197528, D198156

TD: D12222V, D133517, D16538S, D17246N, D19710Y, D19711Z, D197120, D197131, D197426, D197437, D197459, D19747B, D19748C, D19749D, D197506, D198156, D198236, D20756H, D20845H

T0159

CS: D115355, D123615

TC: D15846X, D18211G

GS: D115355, D15805O, D18210F, D18211G

TD: D115355, D123615, D15805O, D15846X, D18208L, D18209M, D18210F

T0160

CS: D104494, D10696H, D130847, D130858

TC: D104494, D130847

GS: D10696H, D130847, D130858, D17888F, D178909

TD: D104494, D10696H, D130847, D130858, D13910G, D14086D, D141457, D17888F, D17889G, D178909

T0161

CS: D123626, D12366A, D12368C, D124629, D125359, D12636D, D13629I, D16540M

TC: D10057S, D123626, D13629I, D15504E, D160269, D22442A

GS: D123626, D125359, D130767, D15504E, D15506G, D15761T, D160269, D16540M, D224419, D22442A

TD: D111773, D123626, D125348, D133299, D13482H, D13629I, D13982W, D13993Z, D139940, D16488Z, D16490T, D17251K, D18027I, D18028J, D18029K, D18030D, D18051I, D18052J, D18053K, D18054L, D18055M, D18056N, D18057O, D18058P, D18285Y, D18286Z, D182870, D182881, D182892, D18370U, D18415Q, D18441S, D18766A, D19414T, D19531X, D196525, D19781D, D19782E, D201672, D201683, D201694, D20170X, D20171Y, D20172Z, D201730, D201741, D201752, D20843F, D20940F, D210593, D21466E, D21918L, D21932J, D22030U, D22095B, D22096C, D22097D, D22098E, D22099F, D22100R, D22101S, D22102T, D22103U, D224419, D22442A, D22443B

T0162

TC: D16512I

GS: D13955T, D16512I

TD: D16512I

T0163

GS: D160178, D160189, D16019A

TD: D160178, D160189, D16019A

T0164

TC: D10182W

GS: D10182W

TD: D10182W

T0165

TD: D14670N, D14829S, D14832N

T0166

TC: D15791Z, D21225Z

GS: D156961, D156972, D15791Z, D21225Z

TD: D156961, D156972, D15791Z, D201865, D21225Z, D21487J

T0167

TC: D101791
GS: D101791, D152125
TD: D101791, D133346

T0168

TC: D15470L, D18216L, D22051Z, D220520
GS: D15470L, D15471M, D18216L, D18217M, D18218N, D22051Z
TD: D15470L, D15471M, D18216L, D18217M, D18218N, D20773I, D22051Z, D220520, D220531

T0169

TC: D19411Q
GS: D19411Q
TD: D16914W, D19402P, D19403Q, D19405S, D19406T, D19407U, D19408V, D19409W, D19410P, D19411Q

T0170

GS: D15667W
TD: D133357, D14702E, D15667W

T0171

TC: D220917
GS: D15003Y, D150050, D150083, D220917
TD: D13740G, D15003Y, D150050, D150061, D150072, D150083, D16750U, D220917, D220928

T0172

GS: D168654
TD: D167742, D167764, D168632, D168643

T0173

TC: D10175X
GS: D10175X, D11572A, D11588I, D12377D, D16072F, D183920, D197277, D20888S, D20903A, D21311W, D213605
TD: D10175X, D11572A, D11587H, D11588I, D11589J, D11590C, D11591D, D11592E, D11593F, D11594G, D12377D, D16072F, D16073G, D169748, D183920, D197277, D20060S, D20888S, D20903A, D21311W, D213605

T0174

TC: D15565R
GS: D11588I, D15564Q, D17213E
TD: D11588I, D15563P, D15564Q, D15565R, D15566S, D15721L, D17213E

T0175

TC: D10858H
GS: D10858H, D12917J, D12925J, D14266F

TD: D10858H, D11164Y, D12916I, D12917J, D12922G, D12923H, D12925J, D134167, D13446D, D14266F, D14495Q, D150094, D15820N, D15860V, D16065G, D18215K, D183862, D18409S

T0176

CS: D104665, D10777H, D12850H

TC: D10777H, D12850H

GS: D10777H

TD: D104665, D10777H, D126125, D12850H, D12870L, D14597V

T0177

TC: D19961F

GS: D19959L

TD: D19959L, D19960E, D19961F, D19962G, D22470E

T0178

TC: D10500Q, D20499J

GS: D12150W, D12587L, D20323W, D20403V, D204091, D20420W, D204524, D20468C

TD: D10500Q, D107619, D10780C, D11309X, D11310Q, D11777L, D118036, D11969R, D11970K, D12105R, D12107T, D12114S, D12115T, D12116U, D12117V, D12118W, D12119X, D12120Q, D12130S, D12136Y, D12137Z, D121380, D12144Y, D121471, D121482, D121493, D12150W, D12151X, D12152Y, D121722, D121733, D12189B, D122565, D122576, D122587, D122598, D12293A, D12455A, D12456B, D12457C, D12459E, D124607, D12479I, D12586K, D12587L, D14533F, D19045O, D194825, D194836, D19943D, D20036S, D20320T, D20321U, D20323W, D20324X, D20398F, D20402U, D20403V, D20405X, D20406Y, D204080, D204091, D20410U, D20411V, D20412W, D20413X, D20414Y, D20415Z, D204160, D204171, D204182, D204193, D20420W, D20421X, D20423Z, D204240, D204251, D204262, D204273, D204284, D20430Y, D20431Z, D204320, D204331, D204342, D204353, D204364, D204375, D204386, D204397, D204400, D204411, D204422, D204433, D204455, D204466, D204477, D204488, D204499, D204502, D204513, D204524, D204535, D204546, D204557, D204648, D204659, D20466A, D20467B, D20468C, D204706, D204717, D20494E, D20495F, D20496G, D20497H, D20498I, D20499J, D20500V, D20501W, D20502X, D20503Y, D20504Z, D205050, D205061, D205072, D205083, D205094, D20510X, D20511Y, D20512Z

T0179

CS: D10500Q, D10780C, D11309X, D11310Q, D118036, D12115T, D12118W, D12130S, D12144Y, D122598, D12293A, D204364, D20494E, D20499J

TC: D10500Q, D12114S, D12459E, D124607, D204273, D204284, D204502, D20499J

GS: D10500Q, D107619, D10780C, D12115T, D12457C, D194836, D20036S, D20413X, D20421X, D204240, D204251, D204273, D204284, D204353, D204364, D204386, D204400, D204433, D204466, D204477, D204499, D204502, D204513, D204546, D204557, D20494E, D20499J

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T0180

CS: D20420W, D204262, D20499J, D20502X, D20503Y, D20665F

TC: D10500Q, D20499J, D20502X, D20503Y, D207045

GS: D204171, D204182, D204193, D20501W, D20503Y, D207023, D207034

TD: D10500Q, D10780C, D12105R, D12114S, D121380, D121471, D121722, D12189B, D19045O, D20320T, D20401T, D20410U, D20413X, D204171, D204182, D204193, D20420W, D204262, D204273, D204375, D204422, D204455, D204488, D204502, D204513, D204535, D204648, D204659, D20466A, D20467B, D204706, D20495F, D20496G, D20497H, D20498I, D20499J, D20500V, D20501W, D20502X, D20503Y, D205050, D205094, D20665F, D207023, D207034, D207045

T0181

TC: D10174W

TD: D10174W

T0182

TC: D10173V

GS: D10173V, D15595X

TD: D10173V, D12967T, D15595X

T0183

TD: D169420, D169431, D169442, D169453, D169475

T0184

GS: D10172U, D13195D

TD: D10172U, D13195D

T0185

TC: D112889, D13050X, D14546K, D19938G

GS: D13050X, D21553C

TD: D112889, D12382A, D124516, D12695O, D12696P, D12897W, D13050X, D13193B, D145039, D14544I, D14545J, D14546K, D14547L, D14548M, D15284L, D15288P, D16481S, D17868B, D188367, D19938G, D19939H, D19942C, D20959Q, D21552B, D21553C

T0186

TC: D16070D, D21314Z

GS: D13966W, D21314Z

TD: D13966W, D14172A, D16070D, D16149J, D16151D, D16152E, D19041K, D19042L, D19170S, D194370, D200851, D21314Z

T0187

TC: D10171T

GS: D10171T

TD: D10171T

T0188

CS: D17802T

TC: D17804V

GS: D17802T, D17803U

TD: D17802T, D17803U, D17804V, D186725

T0189

TC: D15397T

GS: D15424F

TD: D131475, D15397T, D15423E, D15424F, D15425G

T0190

TC: D16398Y

GS: D11877O, D16398Y

TD: D11877O, D16398Y

T0191

TD: D16399Z

T0192

CS: D14375J, D14376K, D205163

TC: D14357H, D14378M, D205163

GS: D14357H, D14374I, D14378M, D205163

TD: D107095, D14357H, D14373H, D14375J, D14376K, D14377L, D14378M, D14379N, D146009, D14601A, D16323F, D205130, D205141, D205152, D205163

T0193

CS: D116405, D12070X

TC: D116405, D13472F

GS: D116405, D12070X

TD: D116405, D12070X, D13472F, D16366Q, D170149

T0194

CS: D105759, D115333, D11638B, D170149, D17016B, D17240H, D17240H, D185697, D187546, D18968I, D18969J, D18970C, D18972E, D19236T, D19290Z, D19503T, D19505V, D19509Z

TC: D105759, D18968I, D19004F, D19290Z, D19509Z, D203816

GS: D105759, D115333, D11638B, D11639C, D170149, D17240H, D18969J, D19236T, D19290Z, D19417W, D19507X, D19514W, D196365, D20584F

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T0195

CS: D10249Y, D10505V, D10630Z, D11020J, D11020J, D11081W, D123342

TC: D10505V, D11020J
GS: D11020J, D189439
TD: D10249Y, D10505V, D10630Z, D11020J, D11081W, D123342, D17034D, D189439, D18944A

T0196

TC: D15646R
GS: D15646R
TD: D10170S, D15646R

T0197

CS: D12868R, D13300W
TC: D13088B, D13124Y
GS: D12868R, D13124Y, D13300W
TD: D11399F, D12868R, D13088B, D13124Y, D131271, D13300W

T0198

CS: D148930, D17088R, D17090L, D192794
TC: D148930, D17088R, D17090L
GS: D148930, D17088R
TD: D148930, D17088R, D17089S, D17090L, D19280X

T0199

CS: D10540Y, D105453, D11041O, D11043Q, D11044R
TC: D105453, D11041O, D11043Q, D11044R
GS: D105453, D11041O, D11043Q, D11045S
TD: D10540Y, D105453, D11041O, D11043Q, D11044R, D11045S, D14238B, D160021

T0200

TC: D123728, D13821G
GS: D123717, D130290, D13821G, D17458X, D17473W
TD: D10164U, D12039Y, D123706, D123717, D123728, D123739, D12374A, D12375B, D12491E, D130290, D130370, D13821G, D17458X, D17473W

T0201

TD: D15622J, D15623K, D15624L, D15625M, D16401C, D188538

T0202

TC: D10163T
GS: D10163T
TD: D10163T, D12877S

Complete bibliographic citations for these references can be found on the CDROM that accompanies the book. The following abbreviations are used throughout the references: **CS** = cost summaries; **TC** = technology costs; **GS** = general studies; **TD** = technology descriptions.

T0203

TD: D16647W, D16648X

T0204

TC: D10185Z, D126249, D15461K, D15462L
GS: D10185Z, D12855M, D15462L
TD: D10185Z, D10333T, D12625A, D12855M, D13649M, D15461K, D15462L

T0205

TD: D17136I, D17137J

T0206

TC: D10161R
TD: D10161R

T0207

CS: D10697I, D12817G, D13031U
TC: D10177Z, D10697I
GS: D10697I, D10779J, D11835E, D12817G
TD: D10177Z, D10697I, D10779J, D11835E, D12817G, D12862L, D12965R, D12966S, D13267C, D16911T

T0208

CS: D17162K, D17163L, D19051M
TC: D17162K
GS: D17162K, D17163L, D19051M
TD: D142030, D14294J, D16922W, D17162K, D17163L, D19051M

T0209

TD: D10935D, D15537N, D15541J, D16430H, D16431I

T0210

TC: D15538O
TD: D15538O, D15539P, D15540I

T0211

TC: D187717
GS: D187728
TD: D112845, D18710U, D187717, D187728

T0212

CS: D104552, D11217U, D126409, D12726E, D12729H

TC: D104552, D10925B

GS: D11217U, D126409, D12726E, D12729H

TD: D10300K, D104552, D10925B, D12052V, D12053W, D12638F, D126409, D12729H, D12878T, D15093G

T0213

CS: D12757L, D143077, D14343B, D14795Z, D20156Z, D201570, D201592, D201592

TC: D13756O, D14795Z

GS: D12757L, D14343B, D14795Z, D17463U, D201581, D201592

TD: D10311N, D12617A, D12757L, D13470D, D13756O, D141377, D143077, D14339F, D14343B, D14794Y, D14795Z, D147960, D147971, D17463U, D17581Z, D175831, D20156Z, D201570, D201581, D201592

T0214

CS: D10577B, D10579D

TC: D12108U

GS: D10579D, D12112Q

TD: D10577B, D10579D, D12109V, D12112Q, D12113R, D13918O, D14095E

T0215

TC: D152012

GS: D152012

TD: D131282, D13290B, D151020, D151042, D152012

T0216

GS: D165940

TD: D16593Z, D165940

T0217

GS: D16553R

TD: D16553R, D16554S

T0218

CS: D10428Z, D105351, D121959, D134247

TC: D10428Z

GS: D10428Z, D10701X, D121959

TD: D10428Z, D105351, D10611W, D10701X, D121766, D121948, D121959, D12206V, D134247

T0219

TC: D17730U

TD: D177291, D17730U

T0220

TC: D21475F
GS: D19873G, D21476G
TD: D16139H, D16144E, D16145F, D19873G, D19874H, D21475F, D21476G

T0221

TD: D14823M, D14824N, D14826P, D14828R

T0222

CS: D15638R
TC: D15638R
GS: D15637Q, D15638R
TD: D15637Q, D15638R

T0223

TC: D10156U
GS: D10156U
TD: D10156U

T0224

TC: D133459, D13609E, D14344C, D20947M
GS: D133459, D13607C, D136107, D136118, D14344C, D20946L, D20947M
TD: D11649E, D133459, D13607C, D13608D, D13609E, D136107, D136118, D136129, D13613A, D13614B, D13615C, D13713D, D140749, D14267G, D14268H, D14344C, D20946L, D20947M

T0225

CS: D115355, D123615
TC: D10149V, D11139X
GS: D115355, D19282Z
TD: D10146S, D10621Y, D11139X, D115355, D123615, D19281Y, D19282Z, D192830, D192841

T0226

TC: D120661, D133517, D177815, D19710Y, D20756H, D20764H
GS: D120650, D123513, D17246N, D19710Y, D197131, D19749D, D20761E
TD: D10845C, D112674, D11270Z, D118014, D120650, D120661, D12221U, D12222V, D12234Z, D123353, D123513, D12864N, D133517, D17246N, D177815, D18245Q, D18278Z, D193811, D19710Y, D197426, D197437, D197448, D197459, D20756H, D20757I, D20758J, D20759K, D20760D, D20761E, D20762F, D20763G, D20764H, D20765I, D20766J, D20767K, D20768L, D20769M, D20770F

T0227

CS: D19710Y, D197437
TC: D120661, D133517, D19710Y, D197437, D20756H, D20764H
GS: D123513, D193811, D19710Y

TD: D112674, D112721, D120650, D122190, D12222V, D12234Z, D123353, D123513, D133517, D17246N, D18390Y, D193811, D19710Y, D197426, D197437, D197448, D197459, D19843A, D20756H, D20757I, D20760D, D20761E, D20762F, D20763G, D20764H, D20766J, D20770F

T0228

TC: D10152Q

GS: D10152Q, D13777T, D13778U

TD: D10152Q, D13777T, D13778U, D17027E

T0229

TC: D177815, D18278Z, D193924, D193957, D19875I, D19877K, D20756H, D21292A, D22474I, D225138, D22515A, D22517C

GS: D18278Z, D193899, D193935, D193979, D19875I, D21481D, D21484G, D21906H, D22475J, D22476K, D225127, D225138

TD: D11262Z, D122190, D12220T, D12222V, D177815, D18278Z, D193899, D193902, D193913, D193924, D193935, D193946, D193957, D193979, D19875I, D19876J, D19877K, D203667, D20756H, D20852G, D20861H, D20929K, D20930D, D20931E, D20932F, D20933G, D21054Y, D21292A, D21446A, D21481D, D21483F, D21484G, D21906H, D21949S, D22474I, D22475J, D22476K, D22477L, D22478M, D22479N, D22480G, D225116, D225127, D225138, D225149, D22515A, D22516B, D22517C

T0230

TC: D13539H

GS: D13539H, D13830H, D20855J, D212384, D213252

TD: D10142O, D132376, D13538G, D13539H, D13540A, D13541B, D13828N, D13829O, D13830H, D13946S, D14434D, D14435E, D14883Y, D14884Z, D20855J, D212384, D213252

T0231

CS: D13051Y, D17212D

TC: D130392, D15743R, D17212D

GS: D130392, D13051Y, D17212D

TD: D12973R, D12974S, D12975T, D12976U, D12978W, D12980Q, D130392, D13040V, D13051Y, D13052Z, D15743R, D15744S, D15900M, D17212D

T0232

TC: D18897K, D20304T

GS: D15809S, D15812N, D15813O, D20304T, D20305U, D20306V, D20307W, D20310R

TD: D15807Q, D15808R, D15809S, D15810L, D15811M, D15812N, D15813O, D15814P, D15815Q, D17465W, D175875, D175886, D18897K, D20304T, D20305U, D20306V, D20307W, D20308X, D20309Y, D20310R, D20311S

T0233

TC: D22449H

TD: D14011U, D150243, D15181F, D17069O, D22450A, D225218

T0234

TD: D16182K

T0235

TC: D168869, D16888B

GS: D168869, D16888B

TD: D167731, D168869, D16887A, D16888B, D16889C, D168905

T0236

CS: D10770A, D11729D, D12041S, D12500Y, D12696P

TC: D10137R, D19938G, D21596N, D21599Q

GS: D10135P, D10770A, D11729D, D12041S, D12500Y, D13298J, D13676P, D14282F, D15732O, D15733P, D16058H, D16481S, D17274R, D17868B, D18418T, D19935D, D19938G, D19944E, D20863J, D21033T, D212453, D21553C

TD: D10135P, D10136Q, D10137R, D10139T, D10676D, D10764C, D10770A, D10794I, D11205Q, D112889, D11676H, D11729D, D11872J, D11920A, D12041S, D123524, D123535, D123557, D123819, D12382A, D12383B, D12449C, D124516, D12497K, D12498L, D12499M, D12500Y, D125246, D125257, D12547D, D12548E, D12579L, D126089, D12694N, D12695O, D12696P, D12824F, D12845K, D12867Q, D12897W, D12904E, D130494, D13050X, D13113V, D131613, D131624, D131635, D131657, D13193B, D132150, D13298J, D13438D, D13474H, D13476J, D13492J, D135002, D135068, D13622B, D13624D, D13659O, D13673M, D13674N, D13675O, D13676P, D140363, D140385, D140410, D14176E, D14253A, D14282F, D14283G, D143099, D14477O, D145006, D145039, D14544I, D14545J, D14546K, D14547L, D14548M, D14577R, D14615G, D14616H, D14618J, D14700C, D14803I, D15275K, D15276L, D15282J, D15284L, D15288P, D15289Q, D15415E, D15484R, D15707N, D15708O, D15731N, D15732O, D15847Y, D158661, D158672, D16058H, D16160E, D163019, D16481S, D167811, D167822, D16824V, D17205E, D17209I, D17216H, D17274R, D17811U, D17867A, D17868B, D17869C, D178705, D183931, D18418T, D18419U, D18420N, D18443U, D185471, D18602R, D186554, D187240, D188367, D18987L, D18988M, D19082T, D19223O, D199159, D19935D, D19936E, D19937F, D19938G, D19939H, D19940A, D19941B, D19942C, D19943D, D19944E, D20744D, D20745E, D20774J, D20863J, D20959Q, D21033T, D212453, D21552B, D21553C, D21595M, D21596N, D21597O, D21598P, D21599Q, D21906H, D22094A

T0237

GS: D15281I

TD: D11872J, D12900A, D14176E, D14615G, D14618J, D15281I, D15283K, D15861W, D16484V

T0238

CS: D10770A, D11729D, D12696P

TC: D10137R, D12696P, D12897W, D19939H

GS: D10135P, D10137R, D10770A, D11729D, D12696P, D13298J, D16481S, D17868B, D185471, D19935D, D212464, D21909K, D21910D

TD: D10135P, D10136Q, D10137R, D10676D, D10764C, D10770A, D11729D, D12382A, D12449C, D124516, D12694N, D12695O, D12696P, D12897W, D12904E, D13298J, D140385, D145006, D15284L, D15288P, D15289Q, D16481S, D17868B, D185471, D188367, D19935D, D19938G, D19939H, D19943D, D20744D, D20745E, D20774J, D20959Q, D21011N, D21016S, D21051V, D212464, D21595M, D21598P, D21599Q, D21908J, D21909K, D21910D

T0239

TC: D10139T, D126089, D131624, D19938G

GS: D12867Q, D15415E

TD: D10139T, D123535, D12382A, D124516, D12579L, D126089, D12695O, D12696P, D12867Q, D130494, D131613, D131624, D131635, D13438D, D15284L, D15415E, D15484R, D16481S, D17868B, D188367, D19938G, D19939H, D20959Q

T0240

Case Study: D11559D

TC: D115424, D115515, D116154, D18248T, D207307

GS: D111740, D11559D, D12597N, D193560, D20729E, D207307

TD: D10138S, D11008N, D111740, D115424, D115515, D11557B, D11559D, D116132, D116154, D121551, D12549F, D12597N, D12670F, D12743F, D12815E, D12856N, D13004R, D13186C, D133506, D13397L, D140374, D18248T, D19015I, D19266Z, D193560, D20728D, D20729E, D207307

T0241

TC: D214095, D214142

GS: D18621U, D186270, D186281, D186292, D18634Z, D18797H, D19772C, D214095, D21410Y, D214120, D214142, D214153

TD: D18621U, D18622V, D18623W, D18624X, D18625Y, D18626Z, D186270, D186281, D186292, D18630V, D18631W, D18632X, D18633Y, D18634Z, D18797H, D19772C, D21392D, D214073, D214084, D214095, D21410Y, D21411Z, D214120, D214131, D214142, D214153

T0242

CS: D12796S, D12798U, D128007, D128029, D128029, D187160, D22123Y, D221578

TC: D128007, D128029, D187160, D22124Z

GS: D12795R, D12797T, D128029, D12829K, D16908Y, D187160, D188378, D188403, D22104V, D22107Y, D22111U, D22112V, D221181, D22120V, D22123Y, D221250, D221283, D221578

TD: D10134O, D10434X, D10703Z, D107040, D12795R, D12796S, D12798U, D12799V, D128018, D128029, D13915L, D14181B, D142325, D14872V, D160043, D16574W, D18441S, D187160, D188378, D188389, D18839A, D188403, D18991H, D213605, D22104V, D22105W, D22106X, D22107Y, D22108Z, D221090, D22110T, D22111U, D22112V, D22113W, D22114X, D22115Y, D22116Z, D221170, D221181, D221192, D22120V, D22121W, D22122X, D22123Y, D22124Z, D221250, D221261, D221272, D221283, D221578

T0243

TC: D10133N

TD: D10133N

T0244

TC: D10132M

TD: D10132M

T0245

TC: D10131L

TD: D10131L

T0246

TC: D10130K

TD: D10130K

T0247

TC: D17644X

GS: D17275S, D17277U

TD: D17275S, D17276T, D17277U, D17278V, D17279W, D17280P

T0248

TC: D141344, D18003A, D18004B, D21009T

GS: D18003A, D21009T

TD: D10677E, D10773D, D141344, D17997J, D17999L, D180007, D180018, D180029, D18003A, D18004B, D21009T, D21016S

T0249

GS: D15627O

TD: D12968U, D15627O, D18306M, D18307N, D18308O

T0250

TD: D10678F

T0251

No references

T0252

GS: D16606N, D16607O, D16608P, D16611K

TD: D16603K, D16604L, D16605M, D16606N, D16607O, D16608P, D16609Q, D16610J, D16611K, D16612L

T0253

GS: D10129R

TD: D10129R, D15790Y

T0254

CS: D16274N

TC: D16320C

GS: D16274N, D176754, D176776, D188141

TD: D16272L, D16273M, D16274N, D16275O, D16320C, D176754, D176765, D176776, D18598C, D18712W, D188130, D188141

T0255

TC: D21213V

GS: D19589F, D21213V, D22204Y

TD: D18065O, D19588E, D19589F, D195908, D19878L, D21213V, D22204Y

T0256

TC: D10127P, D10242R

GS: D10242R, D123808, D12599P, D13121V
TD: D10242R, D123808, D12599P, D12853K, D130949, D13121V

T0257

GS: D16624P, D16625Q
TD: D16624P, D16625Q

T0258

CS: D10126O, D14286J, D14287K, D14288L, D14289M
TC: D14286J
TD: D14286J, D14287K, D14288L, D14289M, D15071A

T0259

CS: D107302, D11818D, D124549, D13310Y
TC: D124549
GS: D107302, D11494D
TD: D107302, D11494D, D11818D, D124549, D125326

T0260

TC: D10120I, D14528I
GS: D10120I, D14528I
TD: D10120I, D10123L, D14528I

T0261

TC: D17074L
TD: D17074L, D17075M

T0262

CS: D10601U, D112594, D12141V, D13033W, D16999H, D170003, D18512Q, D19238V
TC: D11180Y, D112572, D12141V, D18512Q, D20697N
GS: D112594, D12141V, D16999H, D18512Q, D19238V, D20690G, D20691H, D20692I, D20693J
TD: D10601U, D11180Y, D112572, D112583, D112594, D12017S, D12061W, D12141V, D123295, D12330Y, D13033W, D132321, D16999H, D170003, D18512Q, D18811Y, D188265, D19230N, D19238V, D19788K, D203678, D205334, D20688M, D20689N, D20690G, D20691H, D20692I, D20693J, D20694K, D20695L, D20696M, D20697N, D20698O, D20699P, D207001, D207012

T0263

GS: D14615G
TD: D14615G, D15611G

T0264

TD: D14617I, D15742Q

T0265

GS: D14615G, D14618J
TD: D14615G, D14616H, D14618J, D14700C, D15707N, D15708O

T0266

TC: D15804N
GS: D10114K, D15804N
TD: D10114K, D11156Y, D15802L, D15803M, D15804N

T0267

GS: D16311B, D16314E
TD: D152318, D16311B, D16314E, D16444N, D16445O

T0268

GS: D16315F, D16317H
TD: D16315F, D16316G, D16317H, D16318I, D16495Y

T0269

TC: D10121J, D126067
GS: D10121J
TD: D10121J, D126067, D12754I, D12859Q, D13115X, D17741X, D17742Y

T0270

TC: D16670V
GS: D16670V
TD: D16670V, D17185R

T0271

CS: D107051, D12777P, D12778Q, D14255C, D14579T, D169293, D169362, D18323N, D18348W, D18536Y, D19209Q, D20090Y, D206268

TC: D12777P, D12778Q, D14255C, D14522C, D169362, D20090Y, D20317Y, D206268, D21296E, D213354

GS: D107051, D12778Q, D12780K, D14522C, D14579T, D16931X, D169362, D19209Q, D21296E, D224408

TD: D107051, D12777P, D12778Q, D12779R, D12780K, D13123X, D13967X, D140283, D14255C, D14346E, D14522C, D14578S, D14579T, D169282, D169293, D16931X, D16932Y, D16933Z, D169340, D169351, D169362, D175900, D18303J, D18310I, D18322M, D18323N, D18348W, D18534W, D18536Y, D19205M, D197277, D20090Y, D20317Y, D206268, D212668, D21296E, D21299H, D213354, D224408, D22451B, D22452C

T0272

TD: D18705X, D18706Y, D18707Z, D187080, D187091

T0273

TC: D15145B

GS: D15146C
TD: D10679G, D15145B, D15146C, D15480N

T0274

GS: D134418
TD: D134418, D14032Z

T0275

CS: D13884V
TC: D10111H, D13884V, D140181
GS: D13884V, D14015Y
TD: D10111H, D13786U, D13790Q, D13884V, D14016Z, D140170, D140181, D140192

T0276

TC: D11597J, D16903T
GS: D11597J, D16902S
TD: D11597J, D16902S, D16903T

T0277

TC: D17796C, D17801S, D18893G
GS: D17796C, D17799F, D18893G, D20260Y
TD: D17796C, D17797D, D17798E, D17799F, D17800R, D17801S, D18893G, D202573, D202584, D202595, D20260Y

T0278

TD: D15728S

T0279

CS: D18061K, D18062L
TC: D18061K, D18062L, D187375
GS: D18061K, D187375, D220553, D220564
TD: D18061K, D18062L, D18063M, D18064N, D186667, D187375, D220553, D220564

T0280

CS: D13692P, D13694R
TC: D13692P
GS: D13692P, D13693Q, D13694R
TD: D11306U, D13692P, D13693Q, D13694R, D143419

T0281

GS: D15766Y, D15767Z, D178589, D17859A
TD: D15766Y, D15767Z, D178567, D178578, D178589, D17859A

T0282

TC: D10409W
GS: D10409W, D152147, D185733
TD: D10409W, D13908M, D152147, D15387R, D185733, D186601, D19305P, D19306Q

T0283

TC: D22428C
TD: D17068N, D22428C

T0284

TD: D14875Y, D15170C

T0285

TC: D10103H
GS: D10029O, D10103H
TD: D10029O, D10103H, D13637I, D140669, D14279K, D14875Y, D15529N

T0286

GS: D13465G
TD: D13465G

T0287

GS: D16408J
TD: D13464F, D16408J

T0288

TC: D12439A, D12827I
GS: D10789L, D12827I
TD: D10022H, D10789L, D12439A, D12811A, D12827I

T0289

TC: D16385T
GS: D16384S, D17714U
TD: D16384S, D16385T, D16454P, D176787, D17714U

T0290

TC: D10119P
GS: D10119P
TD: D10119P

T0291

TC: D14482L, D15456N
GS: D13125Z, D14482L, D15456N
TD: D13125Z, D14482L, D15456N, D15568U

T0292

CS: D11576E, D11577F, D11579H, D11580A, D11582C, D11873K, D13382E, D18981F

TC: D18981F, D20300P

GS: D11579H, D121460, D18981F

TD: D11575D, D11576E, D11577F, D11578G, D11579H, D11580A, D11582C, D11873K, D121460, D13382E, D18981F, D20300P

T0293

TC: D17794A, D203554

GS: D177928, D18601Q, D20051R, D20978T, D212533, D212544, D212555, D213365, D21477H

TD: D177917, D177928, D177939, D17794A, D17795B, D18601Q, D18888J, D192852, D192863, D192874, D20051R, D203532, D203543, D203554, D203565, D20978T, D212533, D212544, D212555, D213365, D21477H, D21936N

T0294

TC: D19594C

GS: D11487E, D11488F, D17236L, D17237M, D17238N, D17239O, D192874, D19594C, D21937O

TD: D11486D, D11487E, D11488F, D12024R, D12025S, D17236L, D17237M, D17238N, D17239O, D192852, D192863, D192874, D19594C, D212544, D21937O, D21939Q, D21940J

T0295

TC: D10109N

GS: D10109N

TD: D10109N, D13759R, D16367R

T0296

TD: D15592U

T0297

CS: D11311R, D11313T, D11314U, D197277

TC: D11314U

GS: D11070T, D11314U, D12153Z, D201876, D201887, D201898, D201912, D201923, D201934, D201956, D201989, D20199A

TD: D107062, D11070T, D11311R, D11313T, D11314U, D12145Z, D12153Z, D197277, D20127U, D201876, D201887, D201898, D201901, D201912, D201923, D201934, D201945, D201956, D201967, D201989, D20199A

T0298

CS: D16518O, D16521J

GS: D16521J

TD: D16518O, D16519P, D16520I, D16521J

T0299

CS: D14610B, D14613E, D15347J, D17812V

TC: D14598W, D14610B, D14611C

GS: D14611C, D17812V

TD: D12748K, D14598W, D14610B, D14611C, D14612D, D14613E, D14614F, D150469, D150505, D17812V

T0300

TC: D10104I

GS: D10104I

TD: D10104I, D10105J, D14491M, D14492N, D14494P

T0301

TD: D16620L

T0302

GS: D11459A, D12301T

TD: D11459A, D12301T, D16643S, D16644T

T0303

TC: D14701D

GS: D13857S

TD: D13661I, D13855Q, D13856R, D13857S, D16150C

T0304

TC: D189031, D19764C

GS: D189031, D189042

TD: D189031, D189042, D189053, D189064, D19763B, D19764C, D201763

T0305

TC: D178523

TD: D178523

T0306

GS: D11728C, D11764G

TD: D10775F, D11728C, D11764G, D14175D

T0307

CS: D10957J

TC: D10957J

GS: D10957J, D13695S, D14534G, D21300T

Complete bibliographic citations for these references can be found on the CDROM that accompanies the book. The following abbreviations are used throughout the references: **CS** = cost summaries; **TC** = technology costs; **GS** = general studies; **TD** = technology descriptions.

TD: D104676, D10501R, D107073, D10957J, D133368, D13632D, D13695S, D137019, D13702A, D13703B, D141231, D14471I, D14534G, D197277, D20686K, D21300T

T0308

CS: D10102G, D13100Q

TC: D10102G, D11400R

GS: D10102G, D11400R, D13100Q, D197608, D20896S

TD: D10102G, D11400R, D13100Q, D197608, D20896S

T0309

TC: D14012V

GS: D14012V, D15269M, D167866

TD: D14012V, D15269M, D167855, D167866

T0310

CS: D10440V, D108010, D12907H, D130665, D130676, D13672L, D13672L

TC: D13916M, D161217

GS: D12907H, D130676, D161217

TD: D12907H, D130665, D130676, D13916M, D161217, D16561R

T0311

CS: D17169R, D17170K, D19034L, D213332, D214437, D21474E

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GS: D17169R, D17170K, D213332, D21474E

TD: D13862P, D13863Q, D16917Z, D169180, D169191, D16920U, D16921V, D17168Q, D17169R, D17170K, D19034L, D213332, D214437, D214608, D21474E

T0312

TC: D19354Y, D19355Z, D213332, D21474E

GS: D19354Y, D19355Z, D213332, D21474E

TD: D19316S, D19317T, D19318U, D19354Y, D19355Z, D213332, D21474E

T0313

TC: D222220

GS: D16631O, D222220

TD: D16631O, D16827Y, D222220, D222628, D222639

T0314

CS: D120821

TC: D120821

GS: D11992Q, D120810, D120821, D120832, D18363V

TD: D11556A, D11565B, D11755F, D11756G, D11868N, D11976Q, D11985R, D11992Q, D120810, D120821, D120832, D18363V, D18364W

T0315

TD: D127219, D12722A, D12808F

T0316

TC: D130927
GS: D130916, D14490L, D15548Q
TD: D130916, D130927, D130938, D13532A, D13662J, D14490L, D15547P, D15548Q

T0317

TC: D19592A, D19593B
GS: D195919, D19592A, D19593B
TD: D195919, D19592A, D19593B

T0318

CS: D10054P, D10054P, D150130
TC: D10054P, D213332
GS: D10054P, D12556E, D20151U, D20152V, D20153W, D213332
TD: D10054P, D10585B, D107288, D12553B, D12554C, D12555D, D12556E, D12557F, D13862P, D150130, D18693A, D18721X, D20151U, D20152V, D20153W, D20154X, D20155Y, D207409, D213332

T0319

CS: D14490L
TC: D130916, D130927, D14490L
GS: D14490L
TD: D130916, D130927, D130938, D13532A, D14490L, D15547P, D15548Q

T0320

CS: D12909J, D13937R, D13969Z, D142212, D15496V
TC: D12909J
GS: D12909J, D141435
TD: D12909J, D13937R, D13969Z, D141435, D142212

T0321

TC: D20841D
GS: D20839J, D20840C, D20841D
TD: D20839J, D20840C, D20841D

T0322

TD: D14713H

T0323

TC: D10101F
GS: D14731J
TD: D10101F, D14731J

T0324

TD: D10100E

T0325

TC: D20225V, D205403
GS: D13113V, D15729T, D20888S
TD: D13113V, D15729T, D158901, D15903P, D16364O, D201865, D20225V, D205403, D20888S

T0326

CS: D106809, D15199P
TC: D15199P
GS: D106809, D15199P
TD: D100992, D106809, D15199P, D16913V

T0327

CS: D10440V, D108010, D12907H, D130665, D130676, D13672L, D13672L
TC: D12907H, D130676
GS: D108010, D12907H, D130665, D130676
TD: D108010, D12907H, D130665, D130676, D130687, D13558K, D13559L, D13560E, D13570G, D13672L

T0328

TC: D15198O
GS: D15197N
TD: D13141Z, D14539L, D15197N, D15198O, D152056

T0329

CS: D11985R
TC: D11985R
GS: D115548, D11975P, D11976Q, D11977R, D11985R, D11987T, D11991P, D14565N
TD: D115548, D115559, D115628, D11755F, D11756G, D11760C, D11868N, D11973N, D11975P, D11976Q, D11977R, D11985R, D11987T, D11991P, D14565N

T0330

GS: D17161J
TD: D17161J

T0331

CS: D13822H
TC: D100970
GS: D13822H
TD: D100970, D13822H, D15614J

T0332

TC: D17156M, D17183P

GS: D17156M, D17158O

TD: D17155L, D17156M, D17157N, D17158O, D17159P, D17160I, D17183P, D205276

T0333

CS: D18766A, D18766A

TC: D12376C, D186612, D18766A, D200964, D21045X, D22442A

GS: D12376C, D169544, D169555, D185493, D18551X, D18766A, D200964, D21045X, D22444C

TD: D123626, D12376C, D169544, D169555, D17007A, D17008B, D17251K, D18370U, D185493, D18551X, D186612, D18766A, D188436, D188447, D188458, D18849C, D188505, D19003E, D19070P, D200964, D21045X, D22442A, D22443B, D22444C

T0334

TC: D10096Z, D13379J

GS: D13294F, D13379J, D21439B

TD: D10096Z, D12569J, D13294F, D13379J, D14483M, D21439B, D214404

T0335

TC: D10710Y, D12569J, D12572E, D17048J, D19370Y, D21472C

GS: D12569J, D12570C, D17048J, D19248X, D19370Y, D21471B, D21472C, D21473D

TD: D104483, D10710Y, D12568I, D12569J, D12570C, D12571D, D12572E, D13294F, D17048J, D19248X, D19370Y, D21471B, D21472C, D21473D

T0336

CS: D13294F, D13537F, D13836N

TC: D10710Y, D12569J, D12572E

GS: D214415

TD: D12568I, D12569J, D12570C, D12572E, D13292D, D13294F, D13537F, D13735J, D13832J, D13833K, D13834L, D13835M, D13836N, D13837O, D13838P, D13839Q, D13939T, D141446, D214415

T0337

CS: D15732O, D15733P, D20958P

TC: D13496N, D13659O, D17868B, D178705, D19938G, D20958P

GS: D15732O, D15733P, D17868B, D178705, D20686K, D20958P, D20961K, D20962L

TD: D10137R, D123546, D12382A, D124516, D12696P, D12897W, D130494, D13113V, D13659O, D13660H, D140363, D140410, D143099, D15284L, D15731N, D15732O, D15733P, D15847Y, D158661, D158672, D16481S, D17811U, D17867A, D17868B, D17869C, D178705, D188367, D19044N, D19938G, D19939H, D19943D, D20686K, D20958P, D20959Q, D20960J, D20961K, D20962L, D21599Q, D21909K

T0338

TD: D10092V

T0339

GS: D10093W
TD: D10093W

T0340

TD: D10091U, D14876Z

T0341

TC: D10094X
GS: D10094X
TD: D10094X

T0342

TD: D10681A, D14532E

T0343

CS: D152158, D15318E, D17651W
TC: D11871I, D15319F
GS: D152158, D15318E, D15319F, D17651W
TD: D11871I, D12046X, D152158, D15318E, D15319F, D15426H, D17651W

T0344

CS: D123320, D143022, D16986C, D16988E, D169908, D16993B, D17643W, D176492, D17650V
TC: D10857G, D123320, D13589R, D136016, D18248T, D20116R, D205334, D20675H
GS: D123320, D134032, D13593N, D13597R, D16986C, D16987D, D16988E, D16993B, D20675H
TD: D104836, D10711Z, D10857G, D123320, D134032, D13589R, D13590K, D13591L, D13592M, D13593N, D13595P, D13596Q, D13597R, D13598S, D13599T, D136005, D136016, D13754M, D13755N, D14112Y, D143022, D14520A, D158821, D16986C, D16988E, D16989F, D169908, D169919, D16992A, D16993B, D16994C, D17643W, D176492, D18248T, D188414, D188425, D18986K, D19017K, D19068V, D19309T, D197277, D198178, D20116R, D20300P, D205334, D20675H, D20771G, D21225Z

T0345

TC: D17164M, D17167P
GS: D17164M, D17165N, D17166O
TD: D17164M, D17165N, D17166O, D17167P

T0346

TD: D14249E, D15356K, D15357L, D15359N, D15360G

T0347

TD: D141606, D15649U

T0348

TC: D106503, D13377H

GS: D106503, D130803, D21934L

TD: D106503, D11423Y, D13079A, D130803, D13377H, D19932A, D21020O, D21934L, D21935M

T0349

GS: D16116A

TD: D16116A, D16117B, D16118C, D16163H, D179275

T0350

GS: D16247K

TD: D16247K

T0351

CS: D13865S, D13866T

TC: D10587D, D13865S

GS: D13862P, D13863Q, D13864R, D13866T, D13867U, D13869W, D13949V, D20736D

TD: D10054P, D10587D, D12304W, D131668, D13862P, D13863Q, D13864R, D13865S, D13866T, D13867U, D13868V, D13869W, D13949V, D14192E, D20736D, D207409

T0352

CS: D12561B, D12561B, D12987X, D12987X, D20300P

TC: D11672D

GS: D12561B, D18325P, D20300P, D205527

TD: D106150, D11672D, D12559H, D12560A, D12561B, D12987X, D18325P, D20300P, D205527, D20676I

T0353

TC: D176958, D18882D, D203747, D206235

GS: D13864R, D203747, D206235

TD: D10054P, D13864R, D13865S, D13866T, D13949V, D176958, D17697A, D17698B, D18535X, D185380, D196354, D196467, D196478, D196489, D203747, D206235, D213332

T0354

CS: D10085W, D13095A, D169828, D17911X, D179140, D179162, D221556, D221567

TC: D10085W, D11494D, D169839, D16985B, D17911X, D17912Y, D20080W, D221476

GS: D10085W, D107131, D11484B, D11513Z, D11937J, D12131T, D169839, D16984A, D16985B, D17913Z, D179162, D185722, D18715Z, D20080W, D20147Y, D21301U, D21486I, D221476, D221487, D221501, D221512, D221545

TD: D10085W, D10086X, D107131, D11161V, D11170W, D11401S, D11484B, D11485C, D11494D, D115151, D11937J, D11946K, D12131T, D12294B, D12296D, D13095A, D169828, D169839, D16985B, D17911X, D17912Y, D17913Z, D179140, D179151, D179162, D18196Y, D185722, D18715Z, D19037O, D20080W, D20147Y, D21301U, D21486I, D221476, D221487, D221498, D221501, D221512, D221523, D221534, D221545, D221556, D221567

T0355

CS: D141173, D141253

TC: D10944E, D14920M, D16494X

GS: D141173, D141253, D14920M, D16424J, D18696D, D192783

TD: D10944E, D139940, D139951, D140421, D141173, D141253, D14917R, D14920M, D14921N, D16488Z, D18697E, D192783

T0356

GS: D16391R

TD: D16388W, D16391R

T0357

TC: D17096R, D18980E

GS: D165995, D17095Q

TD: D16502G, D16503H, D16504I, D16505J, D165995, D17095Q, D17096R, D18980E, D20943I, D20944J

T0358

TC: D17096R, D20300P

GS: D16503H, D16505J, D17095Q, D17131D, D20944J, D20945K

TD: D16502G, D16503H, D16504I, D16505J, D165995, D17095Q, D17096R, D20300P, D20943I, D20944J, D20945K

T0359

CS: D114432, D14298N, D14371F, D18248T, D205243

TC: D114432, D18248T

GS: D114432, D11662B, D14298N, D18112E, D18248T, D18290V, D18291W, D19243S, D205232, D205254

TD: D114432, D11662B, D131500, D13947T, D14298N, D14371F, D14574O, D18111D, D18112E, D18248T, D18290V, D18291W, D19243S, D205185, D205196, D20520Z, D205210, D205221, D205232, D205243, D205254, D205265

T0360

TC: D14773T, D21577K, D21578L

GS: D14774U, D14775V, D17751Z, D189268, D20054U, D21577K, D21578L

TD: D11162W, D14764S, D14765T, D14766U, D14767V, D14768W, D14769X, D14770Q, D14771R, D14772S, D14773T, D14774U, D14776W, D14777X, D15759Z, D17751Z, D18344S, D189268, D20054U, D203601, D214175, D21577K, D21578L

T0361

TC: D21577K, D22442A

GS: D15761T, D189268, D21577K

TD: D123626, D139940, D14777X, D15760S, D15761T, D17251K, D18344S, D189268, D213230, D21577K, D224419, D22442A, D22443B

T0362

TC: D15711J
GS: D16282N, D16303B
TD: D15711J, D16282N, D16283O, D16284P, D16303B, D17455U, D18325P

T0363

CS: D12884R, D12886T, D133200, D13727J, D13728K
TC: D10107L, D12884R, D13727J, D13728K
GS: D12884R, D12886T, D133200, D13727J, D13728K
TD: D10107L, D12886T, D133200, D13726I, D13727J, D13728K

T0364

TC: D10005G, D213718
GS: D10005G, D213718
TD: D10005G, D21366B, D213718, D221589

T0365

TC: D10004F
GS: D10004F, D14431A
TD: D10004F, D14431A, D16613M, D221589

T0366

CS: D144207
TC: D10006H
GS: D10006H, D144207
TD: D10006H, D12918K, D144207, D14433C, D221589

T0367

CS: D10003E, D15902O, D213707
TC: D10003E
GS: D10003E, D13840J, D213707
TD: D10003E, D13840J, D15902O, D213707, D221589

T0368

TC: D10002D, D21041T
GS: D10002D, D10786I, D14432B, D21041T
TD: D10002D, D10517Z, D10786I, D13841K, D14432B, D18544Y, D20998X, D21041T, D212293, D221589

T0369

GS: D14813K, D14814L, D14815M, D14816N
TD: D140283, D14813K, D14814L, D14815M, D14816N

T0370

CS: D11885O, D13525B

TC: D12104Q, D130756, D13140Y, D13528E, D177575

GS: D130734, D13378I, D13475I, D13525B, D13528E, D13619G, D13733H, D14573N, D177575, D198418

TD: D11885O, D130734, D130756, D13140Y, D13378I, D13475I, D13516A, D13517B, D13525B, D13526C, D13619G, D13733H, D140432, D177575, D19226R, D198418

T0371

CS: D12661E, D12662F, D13346A, D186565

TC: D12589N, D13346A, D18441S, D186565, D22179E

GS: D104905, D124323, D124334, D12661E, D20237Z

TD: D10076V, D104905, D10683C, D10771B, D11208T, D124301, D124312, D124323, D124334, D12589N, D12590G, D12643C, D12660D, D12661E, D12662F, D12826H, D131817, D13346A, D14091A, D14197J, D160032, D18441S, D186565, D197277, D20237Z, D21000K, D22178D, D22179E, D221807, D221829, D22183A

T0372

GS: D17878D, D178807, D178829, D179060

TD: D13975X, D141297, D145028, D15818T, D16141B, D16193N, D16516M, D16517N, D17878D, D17879E, D178807, D178818, D178829, D17883A, D179060

T0373

CS: D13706E, D13811E, D13818L, D142289, D14537J, D168585, D187626, D188709, D19399B, D19414T, D196605, D20781I, D20793M

TC: D168574, D168585, D18187X, D188709, D20792L, D20793M

GS: D13299K, D13814H, D16047E, D168574, D188709, D19432V, D196558, D196605, D20778N, D20779O, D20780H, D20783K, D20793M

TD: D132194, D13299K, D13811E, D13814H, D140396, D15056B, D16046D, D16047E, D168574, D168585, D18171P, D18172Q, D18173R, D18174S, D18175T, D18176U, D18177V, D18178W, D18179X, D18186W, D18187X, D18188Y, D18189Z, D18190S, D18191T, D18362U, D187626, D187659, D188709, D18871A, D19270V, D19399B, D19414T, D19432V, D196558, D196605, D197051, D20776L, D20778N, D20779O, D20780H, D20781I, D20783K, D20785M, D20786N, D20787O, D20788P, D20789Q, D20790J, D20791K, D20792L, D20793M, D20795O

T0374

CS: D134087

TC: D10075U, D140465, D14459M, D18292X, D18293Y

GS: D134087, D14459M, D18292X

TD: D10074T, D10075U, D134087, D140454, D140465, D140476, D140487, D140498, D140501, D16143D, D16323F, D18292X, D18293Y

T0375

GS: D13653I, D13654J, D140454, D14345D, D18152M, D18292X, D182950

TD: D13653I, D13654J, D13655K, D140454, D18151L, D18152M, D18292X, D18293Y, D18294Z, D182950

T0376

CS: D16075I
TC: D16076J, D17235K
GS: D16075I
TD: D16074H, D16075I, D16076J, D16077K, D17234J, D17235K

T0377

CS: D104596, D11793L
TC: D104596, D14632H
GS: D104596, D11793L, D14632H
TD: D104381, D104596, D11793L, D12609A, D12858P, D13723F, D13724G, D13725H, D14297M, D14632H, D158865

T0378

TC: D208037, D208048
GS: D16515L, D208037
TD: D16491U, D16513J, D16514K, D16515L, D197073, D208015, D208037, D208048, D20837H, D20838I

T0379

CS: D10050L, D12690J, D12905F, D14097G
TC: D10050L, D14096F, D141151
GS: D12690J, D14097G
TD: D10050L, D12690J, D12905F, D12921F, D14096F, D14097G, D141151, D197277, D198123, D20105O, D20771G, D20772H, D20773I

T0380

TC: D12919L, D14096F, D14097G, D141151
GS: D12690J, D14097G
TD: D12690J, D12905F, D12921F, D14096F, D14097G, D141151

T0381

CS: D10949J, D14499U, D15379R
TC: D15382M
GS: D10949J, D12529B
TD: D10949J, D12215W, D12529B, D14499U, D15379R, D15382M

T0382

CS: D13122W
GS: D13211W, D132434
TD: D13122W, D132434

T0383

CS: D14874X, D17190O, D17192Q, D17197V
TC: D14874X, D17192Q

GS: D14555L, D14556M, D14874X, D17190O, D17191P, D17192Q, D17197V, D17198W, D19059U

TD: D14031Y, D14555L, D14556M, D14557N, D14558O, D14559P, D14860R, D14872V, D14874X, D17190O, D17191P, D17192Q, D17193R, D17194S, D17195T, D17196U, D17197V, D17198W, D19059U

T0384

CS: D10054P, D10054P, D13865S, D13866T, D150130, D213332, D213332, D213332

TC: D10054P, D10587D, D13865S, D213332

GS: D10054P, D12556E, D134123, D13862P, D13863Q, D13866T, D13867U, D20153W, D213332

TD: D10054P, D10585B, D10587D, D10954G, D12304W, D12556E, D134123, D134258, D13862P, D13863Q, D13864R, D13865S, D13867U, D13949V, D140294, D14198K, D150130, D150629, D15428J, D15429K, D15747V, D20151U, D20152V, D20153W, D20155Y, D213332

T0385

CS: D12570C

TC: D10049S

GS: D10049S, D12578K

TD: D10049S, D12578K

T0386

GS: D16737X

TD: D16737X

T0387

TC: D13089C

GS: D10414T, D13089C, D17214F

TD: D10414T, D13089C, D13116Y, D17214F

T0388

CS: D13002P

TC: D13000N, D13001O, D13003Q

GS: D12927L, D13001O, D13002P, D13003Q

TD: D10304O, D12977V, D129980, D129991, D13001O, D13002P, D13003Q, D131522, D133197, D13643G, D14229A, D14245A, D15448N, D15452J, D15477S, D17641U, D176889, D17689A, D176903, D176925, D18382Y

T0389

GS: D10766E

TD: D10766E, D14343B, D15250B

T0390

CS: D14753P, D14755R

GS: D112878, D14753P, D19252T, D20685J

TD: D112878, D14753P, D14755R, D14757T, D16038D, D16039E, D19252T, D19898P, D20684I, D20685J, D20686K, D20687L

T0391

TD: D17805W, D17806X, D17893C

T0392

TD: D167833

T0393

CS: D13730E, D18812Z

TC: D13730E, D152023, D18812Z

GS: D13730E, D14493O, D18812Z

TD: D13202V, D13204X, D13730E, D14493O, D152023, D181980, D18812Z, D18982G

T0394

CS: D14761P, D18192U, D183997

GS: D11200L, D12016R, D13985Z, D14760O, D14761P, D18193V, D183997

TD: D11200L, D115413, D12015Q, D12016R, D123295, D13985Z, D14179H, D14180A, D14576Q, D14759V, D14760O, D14761P, D14762Q, D18192U, D18193V, D18194W, D183997, D185948, D19230N

T0395

CS: D10584A, D11075Y, D11076Z, D113473, D11499I, D221749, D221749, D22175A

TC: D11075Y, D113473, D18531T, D22175A

GS: D11074X, D11075Y, D11076Z, D113451, D113473, D170309, D18531T, D21486I, D221749, D22175A

TD: D102987, D105839, D10584A, D106558, D11035Q, D11036R, D11037S, D11038T, D11039U, D11040N, D11073W, D11074X, D11075Y, D11076Z, D110770, D11080V, D11342Y, D113451, D113473, D11492B, D11495E, D11499I, D11595H, D11863I, D11936I, D123273, D134269, D14158C, D15328G, D170309, D18531T, D197277, D21486I, D21930H, D221749, D22175A, D22176B, D22177C, D22184B

T0396

TD: D16432J

T0397

CS: D14586S, D14586S

GS: D12200P, D14586S

TD: D12200P, D14585R, D14586S

T0398

CS: D134112, D188709, D188709, D190970, D19304O, D197277, D22041X

TC: D11496F, D122827, D188709, D19096Z, D190970, D22041X

GS: D11496F, D12202R, D12893S, D142358, D188709, D190970, D19304O, D197277, D19784G

TD: D11493C, D11496F, D11817C, D12200P, D12202R, D12885S, D134156, D13634F, D142347, D142358, D142518, D14484N, D188709, D19096Z, D190970, D19304O, D197255, D197313, D197324, D197357, D19738A, D19783F, D19784G, D213376, D21395G, D22041X, D220495

T0399

GS: D19303N
TD: D12200P, D122929, D12880N, D12885S, D16442L, D19303N, D21394F, D21395G

T0400

CS: D104541, D105271, D12684L, D12687O, D12688P, D12803A, D12804B, D12805C, D12809G
TC: D12688P, D12805C
GS: D104541, D10524Y, D105271, D12684L, D12687O, D12689Q, D12805C
TD: D102976, D104541, D10508Y, D105271, D107197, D11309X, D12684L, D12687O, D12688P, D12689Q, D12803A, D12804B, D12805C, D141479, D14199L, D14533F, D16357P

T0401

TC: D17058L
GS: D17052F, D17059M
TD: D17051E, D17053G, D17054H, D17055I, D17056J, D17057K, D17059M, D17060F

T0402

TC: D130381, D13386I
GS: D13383F, D13384G, D13385H
TD: D130381, D13383F, D13384G, D13385H, D13386I

T0403

TC: D16650R
GS: D16650R
TD: D16650R

T0404

TC: D10710Y, D12569J, D14354E, D17048J, D18730Y, D187397, D18982G
GS: D108098, D14493O, D17048J, D18325P, D18982G, D19206N, D19208P, D19210J, D19211K
TD: D108098, D11734A, D14493O, D152023, D18325P, D183782, D187295, D18982G, D19206N, D19207O, D19208P, D19210J, D19211K

T0405

TC: D167855
TD: D11963L, D11964M, D161228, D161239, D16124A, D168858

T0406

CS: D131362, D131373, D13943P, D13943P, D13943P, D13943P, D13943P, D13943P, D13943P, D13943P, D13943P, D13943P, D13945R, D19326U, D19327V, D19328W, D21373A, D22448G
TC: D11025O, D13943P, D150345, D22449H

Complete bibliographic citations for these references can be found on the CDROM that accompanies the book. The following abbreviations are used throughout the references: **CS** = cost summaries; **TC** = technology costs; **GS** = general studies; **TD** = technology descriptions.

GS: D104778, D12729H, D13113V, D13931L, D13943P, D143179, D150323, D150334, D150345, D150389, D188210, D189315, D196536, D196558, D196569, D19657A, D19658B, D19659C, D196605, D196616, D196627, D196638, D196649, D19678F, D19688H, D19699K, D19700W, D20717A, D20793M, D21985W, D21987Y, D21990T, D21991U, D21993W, D21994X, D21995Y, D21996Z, D219970, D22003R, D22004S, D22005T, D22006U, D22007V, D22010Q, D22011R, D22015V, D22016W, D22017X

TD: D10589F, D11025O, D12287C, D12992U, D13113V, D13301X, D133175, D13929R, D13930K, D13943P, D13968Y, D13980U, D14011U, D14087E, D142416, D14498T, D14785X, D150243, D150301, D150334, D150356, D150367, D150378, D15181F, D15824R, D15828V, D158650, D160076, D16421G, D16580U, D188210, D189315, D19327V, D19328W, D19347Z, D196536, D196569, D19657A, D19658B, D196605, D196616, D196627, D196638, D196649, D19678F, D19688H, D19699K, D19700W, D20717A, D20987U, D21985W, D21987Y, D21990T, D21991U, D21993W, D21994X, D21995Y, D21996Z, D219970, D22003R, D22004S, D22005T, D22006U, D22007V, D22010Q, D22011R, D22015V, D22016W, D22017X, D220495, D22448G, D22450A, D225218

T0407

CS: D107186, D10949J

TC: D10225Q, D10949J, D12529B, D12776O

GS: D10225Q, D10688H, D10949J, D12528A

TD: D10225Q, D10688H, D107186, D108043, D10949J, D114523, D119006, D12489K, D12528A, D12529B, D12538C, D12776O

T0408

CS: D10314Q, D12627C, D12876R, D18561Z, D19687G

TC: D10314Q, D12627C, D12876R, D18561Z, D19687G

GS: D12627C, D12876R, D18561Z, D194483, D19687G

TD: D12627C, D12628D, D132558, D13297I, D18561Z, D194483, D19687G, D198076, D20011J

T0409

CS: D17065K, D18766A, D18766A, D21463B, D21480C

TC: D17063I, D18766A, D21464C, D21478I

GS: D17064J, D17065K, D18766A, D21463B, D21478I, D21480C

TD: D17063I, D17064J, D17065K, D176958, D18766A, D200964, D21463B, D21464C, D21478I, D21479J, D21480C, D22249B, D222504

T0410

GS: D142507, D149900

TD: D142507, D149900, D149911, D149922, D149933

T0411

GS: D108156, D142143

TD: D108156, D142143

T0412

CS: D15576U, D15715N, D15751R, D17265Q, D214051

TC: D15714M, D15751R, D214051

GS: D15576U, D15714M, D15715N, D15751R, D214051

TD: D10767F, D15576U, D15714M, D15715N, D15751R, D15753T, D15755V, D15756W, D15757X, D17265Q, D19460Z, D198098, D214051

T0413

TC: D15752S

TD: D15752S

T0414

TC: D15144A

GS: D15144A

TD: D10684D, D151417, D151439, D15144A

T0415

TD: D141628, D14552I, D14553J

T0416

TC: D188356, D221476

GS: D14861S, D14962W, D15059E, D188356, D194596, D19703Z, D197040, D209018, D221476, D22265B

TD: D10863E, D11852F, D14861S, D14957Z, D149580, D149591, D14960U, D14961V, D14962W, D14963X, D149671, D149693, D14972Y, D149740, D150436, D15059E, D15069G, D188356, D194596, D19602V, D19703Z, D197040, D209018, D221476, D222617, D22264A, D22265B, D22266C

T0417

TC: D140625, D14277I, D15272H

GS: D140625, D14277I

TD: D140625, D14277I, D15271G, D15272H, D169566

T0418

CS: D14067A

TC: D10313P, D14067A

GS: D10313P, D14067A

TD: D10313P, D14067A, D169566

T0419

TC: D14636L

TD: D14636L, D169566

T0420

TC: D14383J, D14386M

GS: D14383J, D14385L

TD: D14383J, D14384K, D14386M, D14387N

T0421

GS: D16601I
TD: D16601I, D16602J, D16899E

T0422

CS: D16600H, D16601I, D17199X
GS: D16600H, D16601I, D17199X
TD: D16600H, D16602J, D16899E, D17199X

T0423

GS: D16600H, D16601I
TD: D16600H, D16602J, D16899E

T0424

TC: D15333D
TD: D15332C, D15333D, D15334E, D15335F

T0425

TC: D15333D
TD: D15332C, D15333D, D15334E, D15335F, D15336G

T0426

TC: D124538, D12663G, D12766M
GS: D12767N, D12768O
TD: D124538, D12659K, D12663G, D12765L, D12767N, D12768O

T0427

TC: D16319J
TD: D13456F, D14640H, D14718M, D161115, D161137, D16319J, D17197V

T0428

TD: D16319J, D18206J

T0429

GS: D14735N
TD: D14735N, D161002

T0430

CS: D17274R
TC: D131657, D13675O, D17274R, D19938G
GS: D13676P, D14282F, D17274R

TD: D12382A, D124516, D12695O, D12696P, D130494, D131657, D132150, D13476J, D13673M, D13674N, D13675O, D13676P, D140385, D14282F, D14283G, D15284L, D15288P, D16481S, D17274R, D17868B, D188367, D199159, D19935D, D19938G, D19939H, D19942C, D20959Q

T0431

TC: D108178
GS: D10301L, D108178
TD: D10301L, D108178

T0432

GS: D16225E
TD: D16225E

T0433

CS: D12807E
TC: D10306Q, D121926
GS: D11494D, D121711, D121755, D12807E
TD: D10306Q, D11494D, D11809C, D121711, D121744, D121755, D121926, D12806D, D12807E

T0434

TD: D16860Z

T0435

TD: D13860N

T0436

TC: D15468R
GS: D15468R
TD: D15468R, D15469S

T0437

TC: D10082T
GS: D10082T
TD: D10082T

T0438

TC: D10084V
GS: D10084V
TD: D10084V

T0439

TC: D13960Q

GS: D13960Q

TD: D134010, D13960Q, D16173J

T0440

TC: D10308S

GS: D10308S

TD: D10308S

T0441

CS: D12879U, D13007U, D13035Y, D130778, D15432F, D15660P, D157884, D17264P, D178749, D179071, D184581

TC: D106172, D184570, D184581, D18464Z

GS: D13007U, D15432F, D15681U, D157884, D157895, D184570, D184581, D18464Z, D18958G

TD: D106172, D13007U, D13098D, D15432F, D15660P, D15681U, D157884, D157895, D15909V, D178738, D178749, D17875A, D17876B, D17877C, D179071, D184570, D184581, D18464Z, D18958G

T0442

TC: D10309T, D19400N

GS: D10309T, D19400N

TD: D10309T, D15686Z, D156870, D19400N

T0443

CS: D16924Y, D16924Y

TC: D16925Z

GS: D16924Y

TD: D16924Y, D16925Z, D169260

T0444

TC: D111900

GS: D10844B, D143408

TD: D10844B, D111900, D143408

T0445

TC: D15853W, D16996E, D19400N, D203816

GS: D15853W, D18528Y, D19400N, D21447B, D22442A

TD: D11082X, D15851U, D15852V, D15853W, D16996E, D18528Y, D19400N, D203816, D21447B, D21456C, D22442A

T0446

GS: D104927, D10515X

TD: D104927, D10515X, D10819A, D16359R

T0447

CS: D12937N, D12941J, D158570, D19496B

TC: D12940I, D19496B

GS: D10406T, D12937N, D12940I, D12941J
TD: D10406T, D10883I, D12937N, D12940I, D12941J, D188152, D194723, D19496B

T0448

CS: D130654, D17211C
TC: D10307R
GS: D10307R, D130654, D14460F, D17211C
TD: D10307R, D10883I, D130654, D14460F, D17211C

T0449

CS: D142096
TC: D12872N
GS: D12872N
TD: D10302M, D11924E, D12872N, D142096, D142165

T0450

CS: D12681I, D12683K, D12683K, D15907T
TC: D12683K
GS: D12681I, D12683K, D15907T
TD: D12681I, D12682J, D12683K, D15907T

T0451

TC: D13468J
GS: D13468J
TD: D13468J

T0452

TC: D10857G, D123320, D13589R, D136016, D14867Y, D18248T
GS: D10028N, D11662B, D126034, D12866P, D134032, D14298N
TD: D10028N, D104836, D10711Z, D11008N, D11662B, D12014P, D123320, D126034, D12866P, D134032, D13592M, D13597R, D136016, D14298N, D14371F, D14862T, D14864V, D14868Z, D18248T

T0453

GS: D140589, D152114
TD: D11305T, D11755F, D12036V, D132310, D140589, D14535H, D152114, D15702I, D15703J, D15704K, D15705L, D15706M, D15717P

T0454

TC: D102965
GS: D102965, D14455I
TD: D102965, D14454H, D14456J, D14692T

T0455

TC: D15491Q

GS: D15491Q, D15577V
TD: D15491Q, D15577V

T0456

CS: D12764K, D14350A
TC: D12584I, D12764K
TD: D12584I, D12764K, D12903D, D135148, D14350A

T0457

TC: D102932
GS: D102932, D12651C
TD: D102932, D12651C

T0458

TC: D18704W
GS: D18702U
TD: D18702U, D18703V, D18704W

T0459

CS: D13107X, D13108Y, D135319, D14860R
TC: D13106W, D13108Y, D135319, D14851Q
GS: D13106W, D13107X, D135319, D14860R, D18273U
TD: D13106W, D13107X, D13108Y, D135319, D13734I, D14851Q, D14860R, D14872V, D18273U

T0460

TC: D13108Y
GS: D13108Y, D13388K
TD: D13106W, D13107X, D13108Y, D13388K, D135319, D147982, D18273U

T0461

TC: D102921
GS: D102921
TD: D102921

T0462

CS: D16228H, D16233E, D16234F, D16239K, D17039I, D17040B, D17041C, D17042D, D17043E, D18778E, D188061, D202686, D202846, D202868, D202879, D202904, D202904

TC: D17040B, D17041C, D18686B, D18804Z, D202686, D202868, D202879

GS: D16228H, D16229I, D16234F, D16239K, D17039I, D18778E, D19799N, D20214S, D202675, D202686, D202697, D202835, D202857, D202868, D20288A, D202904, D202948

TD: D16226F, D16228H, D16229I, D16230B, D16231C, D16232D, D16233E, D16234F, D16239K, D17039I, D17040B, D17041C, D17042D, D17043E, D18686B, D18687C, D18689E, D186907, D18778E, D18803Y, D18804Z, D188050, D188061, D19426X, D19799N, D19800Z, D198010, D20214S, D202675, D202686, D202697, D202700, D202835, D202846, D202857, D202868, D202879, D20288A, D202904, D202948

T0463

CS: D202700, D202824, D202835, D20288A, D20296A

TC: D202824, D20296A

GS: D16227G, D186918, D186929, D202813, D202835, D20288A, D202904, D20296A

TD: D16226F, D16227G, D16229I, D16230B, D16231C, D16232D, D16239K, D18686B, D18687C, D186918, D186929, D18803Y, D188050, D19426X, D19800Z, D202686, D202697, D202700, D202813, D202824, D202835, D202846, D202857, D202868, D20288A, D202904, D20296A

T0464

GS: D16232D, D18687C, D188072, D198010, D202686, D202697, D202835, D202868, D20288A, D202904

TD: D16229I, D16230B, D16231C, D16232D, D16239K, D18686B, D18687C, D18688D, D18689E, D18803Y, D188061, D188072, D19426X, D198010, D202686, D202697, D202700, D202835, D202846, D202857, D202868, D20288A, D202904

T0465

CS: D177360, D179322, D18250N

TC: D17735Z, D177360

GS: D17732W, D17735Z, D177360

TD: D17731V, D17732W, D17735Z, D177360, D179322, D18250N

T0466

TC: D20493D

GS: D20491B, D20492C, D20493D

TD: D20491B, D20492C, D20493D

T0467

CS: D14364G, D14366I, D14368K, D176743, D186598, D18885G, D18886H, D193673

TC: D12104Q, D130905, D14369L

GS: D14364G, D14366I, D14368K, D176743, D186598, D18885G, D18886H, D193673

TD: D102910, D10303N, D10597F, D14364G, D14365H, D14366I, D14367J, D14368K, D14369L, D14469O, D176743, D18275W, D185482, D186598, D18885G, D18886H, D18890D, D19005G, D19079Y, D19105J, D193673

T0468

CS: D14658R, D18102C, D18766A, D18766A, D188709, D22442A

TC: D150447, D18103D, D18766A, D188709, D22442A

GS: D14658R, D14659S, D18102C, D18766A, D188709, D190992, D22442A

TD: D123626, D14657Q, D14658R, D14659S, D14660L, D18101B, D18102C, D18103D, D18553Z, D185562, D18766A, D188709, D190992, D19101F, D21389I, D22442A, D22443B

T0469

GS: D14292H, D15700G

TD: D131511, D14292H, D15700G, D168927

T0470

GS: D17062H

TD: D17062H

T0471

TC: D16251G

GS: D15709P, D16251G, D16253I, D16256L, D201650, D201661, D202653

TD: D15709P, D16250F, D16251G, D16252H, D16253I, D16254J, D16255K, D16256L, D16257M, D16258N, D16263K, D16266N, D20163Y, D20164Z, D201650, D201661, D20261Z, D202620, D202631, D202642, D202653, D202664

T0472

TC: D14069C, D175580

GS: D14069C

TD: D14068B, D14069C, D141617, D175580

T0473

TC: D18455Y, D20844G, D20886Q, D21204U, D22442A

GS: D132343, D16799B, D18441S, D20834E, D20844G, D20886Q, D20887R, D20888S, D20889T, D20891N, D21204U

TD: D123626, D132343, D16770Y, D16798A, D16799B, D18441S, D18455Y, D20833D, D20834E, D20835F, D20844G, D20870I, D20885P, D20886Q, D20887R, D20888S, D20889T, D20890M, D20891N, D20892O, D21204U, D22442A, D22445D

T0474

TC: D120672

GS: D112798

TD: D112798, D120683

T0475

CS: D152067, D152103, D15406D

TC: D152103, D18882D

GS: D140705, D152067, D152089

TD: D140705, D143306, D152067, D152078, D152089, D15209A, D152103, D15406D, D16328K, D17453S, D18720W

T0476

TD: D15472N, D16293Q, D16295S, D17087Q, D187411

T0477

TC: D16178O, D17038H

GS: D162038, D17038H

TD: D16178O, D162038, D17038H, D20686K

T0478

TC: D135035
GS: D108429
TD: D108429, D135035, D135046

T0479

CS: D10290Z, D13762M, D13764O, D13825K
TC: D10290Z, D13764O, D13825K
GS: D10290Z, D13762M, D13825K
TD: D10290Z, D13750I, D13761L, D13762M, D13764O, D13825K, D14010T, D14184E

T0480

CS: D10059U, D10426X, D104687, D104869, D10687G, D11065W, D115344, D115344, D11953J, D11959P, D11961J
TC: D10059U, D10426X, D11953J, D11959P
GS: D115344, D11959P
TD: D10059U, D10426X, D10687G, D11065W, D11959P, D11961J

T0481

GS: D102896
TD: D102896

T0482

GS: D102885, D14159D
TD: D102885, D14159D, D16672X

T0483

TC: D13464F
GS: D13464F, D168916
TD: D13464F, D168916

T0484

CS: D15500A, D15561N, D15562O, D186816
TC: D10159X
GS: D15500A, D15562O, D186816
TD: D10159X, D12865O, D15499Y, D15500A, D15561N, D15562O, D186805, D186816

T0485

GS: D14736O
TD: D12000J, D13275C, D13276D, D13284D, D13457G, D14734M, D14736O, D14737P, D15631K, D170014

T0486

CS: D13201U, D13568M, D13569N

TC: D13201U, D13568M, D13569N, D18769D

GS: D13201U, D13568M, D13569N, D18768C, D18769D

TD: D12821C, D13568M, D13569N, D18423Q, D18768C, D18769D, D187706

T0487

GS: D14685U, D14696X, D19216P

TD: D10263W, D143124, D14685U, D14696X, D18411M, D19216P

T0488

TC: D19938G

GS: D16058H, D19223O, D21033T, D212453

TD: D12382A, D124516, D12696P, D12897W, D15284L, D16058H, D16160E, D16481S, D17205E, D17868B, D188367, D19223O, D19938G, D19939H, D20959Q, D21033T, D212453

T0489

GS: D166863, D18183T

TD: D166852, D166863, D18183T, D18184U, D18185V

T0490

CS: D12013O, D12014P, D14105Z, D18612T

TC: D115479, D12014P, D18612T

GS: D10274Z, D116110, D12013O, D17207G, D18612T

TD: D10274Z, D115479, D116110, D12013O, D12014P, D12232X, D14021W, D14105Z, D17206F, D17207G, D17208H, D17210B, D18248T, D18612T, D19254V

T0491

TC: D17705T, D17707V

GS: D17707V

TD: D17705T, D17707V

T0492

CS: D10250R, D105475, D105486, D107222, D19079Y, D197277, D20013L, D20017P, D20018Q

TC: D105475, D105486, D107222, D19079Y, D20012K, D20014M, D20015N

GS: D105486, D107222, D12378E, D19079Y, D20013L, D20014M, D20016O, D20018Q

TD: D10250R, D105475, D105486, D107222, D12378E, D126001, D127004, D127015, D127026, D13941N, D19079Y, D20012K, D20013L, D20014M, D20016O, D20018Q

T0493

GS: D19082T, D20863J

TD: D167811, D167822, D19082T, D20863J

T0494

CS: D18766A, D18766A

TC: D15553N, D18766A

GS: D15551L, D15593V, D176481, D18766A, D200964, D22427B

TD: D15549R, D15550K, D15551L, D15552M, D15593V, D15594W, D176481, D18766A, D19081S, D200964, D20862I, D220495, D22427B

T0495

TC: D13104U, D13549J

GS: D13006T, D13104U

TD: D13006T, D13096B, D13548I, D13549J

T0496

TC: D18118K

GS: D16369T, D18118K

TD: D14708K, D16369T, D16370M, D16403E, D18118K

T0497

CS: D13573J, D13574K, D13576M

TC: D13579P, D13894X

GS: D13573J, D13574K, D13575L, D13894X

TD: D131351, D13572I, D13573J, D13574K, D13575L, D13576M, D13577N, D13578O, D13579P, D13580I, D13581J, D13894X, D14529J

T0498

CS: D14854T, D14855U, D14856V, D14856V, D14857W, D19079Y, D19079Y, D197277

TC: D106467, D108214, D14855U, D19079Y

GS: D14854T, D14855U, D14856V, D14857W, D19079Y

TD: D106467, D107233, D10769H, D108214, D14469O, D14854T, D14855U, D14856V, D14857W, D19079Y, D197277, D19943D

T0499

CS: D14370E, D14723J, D17642V

TC: D14723J

GS: D14370E, D14723J, D17642V

TD: D13942O, D14356G, D14370E, D14723J, D17642V

T0500

CS: D10503T

TC: D102874, D10503T, D188527

GS: D102874, D10503T, D132514

TD: D102874, D10503T, D130621, D130632, D132514, D13858T, D13942O, D15675W, D18235O, D18375Z, D188527

Complete bibliographic citations for these references can be found on the CDROM that accompanies the book. The following abbreviations are used throughout the references: **CS** = cost summaries; **TC** = technology costs; **GS** = general studies; **TD** = technology descriptions.

T0501

TC: D102841, D15094H
GS: D13368G, D15735R
TD: D102841, D13368G, D15094H, D15734Q, D15736S

T0502

CS: D14568Q, D14593R, D14594S, D20081X
TC: D14567P, D14568Q, D20081X, D21039Z
GS: D14567P, D14568Q, D15385P, D170047, D21039Z
TD: D14567P, D14568Q, D14569R, D14570K, D14591P, D14593R, D14594S, D14595T, D15385P, D170047, D20081X, D21039Z

T0503

GS: D10512U, D10788K, D15648T
TD: D10512U, D10788K, D15648T

T0504

TC: D16379V
GS: D16382Q, D16433K
TD: D16291O, D16379V, D16382Q, D16383R, D16433K, D16434L, D16435M

T0505

TC: D15605I
TD: D11129V, D13355B, D15605I

T0506

CS: D130596
TC: D130563, D130585
GS: D130552, D130585, D130596
TD: D10843A, D130541, D130552, D130574, D130585, D130596, D13371B

T0507

CS: D102863, D12738I, D17025C, D18610R
TC: D12734E, D12736G, D12739J, D12740C, D13497O, D18997N, D205549
GS: D102863, D12733D, D12735F, D12738I, D12739J, D13497O, D174770, D18610R, D205549
TD: D102863, D10416V, D12732C, D12733D, D12734E, D12735F, D12736G, D12737H, D12738I, D12739J, D12740C, D13497O, D139962, D143102, D17025C, D174770, D18610R, D186452, D186463, D18995L, D18997N, D205538, D205549, D20555A

T0508

CS: D126147, D13518C, D135206, D14521B, D16179P
TC: D102852, D126147, D175911
GS: D126147, D13518C, D135206, D170127, D175842

TD: D126147, D13518C, D13519D, D135206, D135217, D13721D, D16179P, D17464V, D175842, D175853, D175911

T0509

CS: D12777P, D12778Q, D206133

TC: D12777P, D12778Q, D16068J, D203689, D20369A, D203703, D203714, D203725, D203736, D203747, D206111, D206224, D206246, D20628A, D20629B, D206304

GS: D12778Q, D16067I, D16566W, D16573V, D203689, D20369A, D203703, D203714, D203725, D203736, D203747, D206075, D206097, D206100, D206122, D206133, D206144, D206188, D206246, D20628A, D20629B, D213354

TD: D12048Z, D12778Q, D13222Z, D132230, D16066H, D16067I, D16068J, D16078L, D16079M, D16080F, D16566W, D16573V, D176958, D181991, D18272T, D18300G, D18301H, D18303J, D18383Z, D187444, D187466, D188232, D18882D, D19274Z, D19444Z, D19576A, D19887M, D200895, D20333Y, D203350, D203689, D20369A, D203703, D203714, D203725, D203736, D203747, D20377A, D206075, D206097, D206100, D206111, D206122, D206133, D206144, D206188, D206224, D206246, D20628A, D20629B, D206304, D213354, D21554D, D21555E

T0510

TC: D10157V

GS: D10157V

TD: D10157V

T0511

TD: D16645U, D16646V

T0512

TD: D167968, D167979

T0513

TD: D16805S

T0514

TC: D15314A, D15317D

GS: D15314A, D15315B, D17459Y

TD: D153139, D15314A, D15315B, D15316C, D15317D, D16137F, D17459Y

T0515

CS: D14705H, D14707J, D16134C

TC: D14705H, D14707J

GS: D14705H, D14707J, D16132A, D16134C, D16136E

TD: D14705H, D14706I, D14707J, D16132A, D16133B, D16134C, D16135D, D16136E, D16137F, D16324G

T0516

TC: D16138G

GS: D16134C
TD: D16132A, D16133B, D16134C, D16138G

T0517

GS: D16132A
TD: D16132A, D16133B, D16136E

T0518

TC: D13628H
GS: D13628H
TD: D13628H, D14651K, D14652L

T0519

TC: D13628H
GS: D13628H
TD: D13628H, D14651K

T0520

TC: D10940A
GS: D15267K
TD: D10940A, D124709, D15267K, D16470P, D16473S

T0521

TD: D15644P, D16436N, D16437O, D16438P

T0522

TC: D10281Y, D13880R, D20031N
GS: D10281Y, D13880R, D13891U, D19612X, D20031N
TD: D10281Y, D13880R, D13891U, D13892V, D19612X, D20031N, D20032O

T0523

TC: D15723N
GS: D15722M, D207318
TD: D12991T, D12993V, D12994W, D15722M, D15723N

T0524

TC: D17135H
GS: D17134G
TD: D17134G, D17135H

T0525

CS: D11980M

GS: D11979T, D11980M, D189246, D195828, D22296I

TD: D11787N, D11966O, D11968Q, D11978S, D11979T, D11980M, D12023Q, D12099A, D14712G, D17032B, D17033C, D18079U, D18889K, D189246, D18998O, D195828, D20686K, D22296I, D22297J, D224077

T0526

TC: D102783, D102794, D10280X

GS: D160327

TD: D102783, D102794, D10280X, D14697Y, D160327

T0527

TD: D102772

T0528

TC: D102761, D22267D, D22268E

GS: D102761, D150050

TD: D102761, D13962S, D150050, D15673U, D22267D, D22268E, D22269F

T0529

CS: D12911D, D12912E, D12913F, D12915H, D13751J, D185664, D20727C

TC: D12910C, D13751J, D185664, D207238

GS: D12914G, D13751J, D160065, D18517V, D185664

TD: D12910C, D12911D, D12912E, D12913F, D12914G, D12915H, D13751J, D160065, D18517V, D185664, D207238, D207249, D20725A, D20726B, D20727C

T0530

TC: D157986, D15848Z, D176572

GS: D157986, D157997, D15800J, D15848Z, D17184Q

TD: D157986, D157997, D15800J, D15801K, D15848Z, D158490, D17179T, D17180M, D17181N, D17182O, D17184Q, D176572, D176594, D17660X, D18441S, D185813, D185824

T0531

GS: D15309D, D153106, D15422D, D174781

TD: D15309D, D153106, D15422D, D174781, D18411M, D18441S, D18616X

T0532

GS: D15242B, D16037C

TD: D13948U, D15242B, D16037C

T0533

TC: D210571, D213376

GS: D132456, D13400Z, D15746U, D18531T, D18614V, D18795F, D189075, D20807B, D210571, D21298G, D213376, D21921G, D21922H, D21925K, D21931I

TD: D130461, D130472, D130483, D131646, D132456, D13400Z, D13792S, D14425C, D15746U, D18531T, D18614V, D18795F, D189075, D20807B, D210571, D21298G, D213376, D21921G, D21922H, D21923I, D21924J, D21925K, D21926L, D21927M, D21928N, D21929O, D21930H, D21931I, D21932J, D21933K

T0534

GS: D16290N

TD: D121584, D15831Q, D16290N

T0535

GS: D116110, D14102W, D141071, D17210B, D18005C, D18008F

TD: D116096, D116110, D12013O, D12014P, D12232X, D14102W, D14103X, D14104Y, D141060, D141071, D141082, D17206F, D17210B, D18005C, D18008F

T0536

CS: D10203K, D10204L, D10205M, D10206N, D10216P, D11055U, D11124Q, D11126S

TC: D18091Q

GS: D10203K, D10204L, D10214N, D10215O, D11048V, D110781, D16671W, D18087U

TD: D10201I, D10203K, D10204L, D10205M, D10206N, D10214N, D10215O, D11048V, D11054T, D11055U, D11110K, D11121N, D11124Q, D11126S, D115468, D15438L, D18087U, D18091Q

T0537

CS: D12041S, D12500Y, D183931, D18418T, D18418T, D18420N, D18602R, D186554, D187240, D187240, D18987L, D18987L, D18988M, D18988M

TC: D12500Y, D18418T, D18443U

GS: D12499M, D125246, D17209I

TD: D12041S, D123557, D12497K, D12498L, D12499M, D12500Y, D125246, D125257, D12547D, D12548E, D17209I, D183931, D18418T, D18419U, D18420N, D18443U, D18602R, D186554, D187240, D18987L, D18988M

T0538

TC: D14800F

GS: D10649A, D14800F

TD: D10649A, D14800F, D15485S, D15486T

T0539

CS: D16179P, D16195P

TC: D16195P

GS: D16179P, D16195P

TD: D16179P, D16180I, D16181J, D16195P

T0540

TC: D18895I, D18983H, D22201V

GS: D160134, D160145, D18896J, D18983H, D22201V, D22202W, D22203X

TD: D12047Y, D160134, D160145, D18895I, D18896J, D18983H, D20300P, D22186D, D22201V, D22202W, D22203X

T0541

TC: D17717X, D220451, D220633, D220699

GS: D186634, D186714, D220451, D220633, D220644, D220699

TD: D17717X, D186634, D186714, D187364, D19104I, D20899V, D220451, D220633, D220644, D220655, D220666, D220677, D220688, D220699, D220702, D220713, D220724, D220735, D220746, D220757, D220768

T0542

TC: D122714

GS: D10272X, D11350Y, D15173F, D20045T, D20047V

TD: D10272X, D11350Y, D122714, D15068F, D150709, D15173F, D20044S, D20045T, D20046U, D20047V

T0543

TD: D13932M, D13933N, D13934O

T0544

CS: D12951L, D12953N, D15453K

TC: D12953N

GS: D10620X, D11303R, D12949R, D12951L, D12953N, D12961N, D12962O, D12963P, D15453K

TD: D10620X, D11303R, D12948Q, D12949R, D12951L, D12953N, D12961N, D12962O, D12963P, D13291C, D13973V, D15453K, D15454L, D15455M

T0545

TC: D17554W, D17555X, D17557Z, D17896F

GS: D17551T, D17553V, D17554W, D17895E, D17899I, D17900U

TD: D17551T, D17552U, D17553V, D17554W, D17555X, D17556Y, D17557Z, D17895E, D17896F, D17897G, D17898H, D17899I, D17900U

T0546

TC: D11322U, D113291, D169602, D17451Q, D17452R, D22026Y

GS: D109024, D11325X, D113291, D11330U, D11940E, D12298F, D134316, D13871Q, D169602, D17282R, D17283S, D17286V, D17287W, D17288X, D17289Y, D17290R, D17451Q, D17452R, D185788, D186543, D194712, D195395, D195497, D195511, D195533, D195657, D195668, D19568A, D19569B, D195704, D195715, D20976R, D21907I

TD: D109024, D11322U, D11323V, D11324W, D11325X, D11327Z, D113280, D113291, D11330U, D11421W, D11816B, D11893O, D11940E, D12298F, D132183, D134316, D13871Q, D13984Y, D14294J, D16577Z, D169373, D169602, D17282R, D17283S, D17284T, D17285U, D17286V, D17287W, D17288X, D17289Y, D17290R, D17451Q, D17452R, D18277Y, D18284X, D18341P, D185755, D185766, D185777, D185788, D185799, D185802, D185846, D185857, D185868, D185879, D18588A, D18589B, D185915, D185926, D185937, D186532, D186543, D18779F, D18782A, D19046P, D19047Q, D19048R, D19055Q, D19056R, D19078X, D194552, D194712, D195373, D195384, D195395, D19540Y, D19541Z, D195420, D195431, D195453, D195464, D195475, D195486, D195500, D195511, D195522, D195533, D195544, D195566, D195577, D195588, D195599, D195602, D195613, D195624, D195635, D195646, D195657, D195668, D195679, D19568A, D19569B, D195704, D195715, D195726, D195737, D195748, D196514, D20143U, D20332X, D20399G, D20400S, D20404W, D20422Y, D204295, D20589K, D20601Z, D206326, D20819F, D20975Q, D20976R, D21554D, D21907I, D21932J, D22022U, D22023V, D22024W, D22025X, D22026Y, D22027Z

T0547

TD: D15588Y

T0548

TD: D15589Z, D15596Y

T0549

TD: D15590S, D155980

T0550

TD: D15591T

T0551

TD: D15587X, D15597Z, D155991, D15600D

T0552

TC: D10303N, D12104Q, D130905, D19079Y
GS: D10303N, D106412, D19079Y, D19837C, D198429
TD: D10303N, D106412, D113917, D114578, D11883M, D12104Q, D130905, D14368K, D14469O, D18441S, D19079Y, D19837C, D19838D, D19839E, D198418, D198429

T0553

TD: D15368O, D15369P, D15479U

T0554

CS: D15585V
TC: D15585V, D18882D
GS: D15581R, D15585V, D15586W, D175820
TD: D15580Q, D15581R, D15582S, D15583T, D15584U, D15585V, D15586W, D17461S, D175820

T0555

TC: D12584I
TD: D12584I, D12764K, D140818, D14381H

T0556

CS: D12583H
TC: D12584I

GS: D12583H, D12764K
TD: D10080R, D12581F, D12583H, D12584I, D12764K, D140818, D14351B, D14381H

T0557

GS: D16674Z
TD: D16674Z, D166761

T0558

TC: D16468V
TD: D16467U, D16496Z, D164992

T0559

TD: D165962, D165973, D165984

T0560

CS: D18701T, D187739
TC: D18700S, D18701T
GS: D18701T, D187739, D18776C
TD: D18699G, D18700S, D18701T, D187739, D18774A, D18775B, D18776C, D18777D

T0561

TD: D16305D, D16306E

T0562

TD: D16307F, D16308G

T0563

CS: D11018P
TC: D11018P
GS: D11018P, D131919
TD: D10530W, D11018P, D131919, D143317

T0564

CS: D17046H, D19057S
TC: D19061O
GS: D19057S, D19063Q, D19064R, D19065S, D19066T, D19067U
TD: D166874, D17046H, D19057S, D19060N, D19061O, D19062P, D19064R, D19066T, D19067U

T0565

CS: D176801, D176823
TC: D15534K, D176823, D20590D, D21579M, D21581G

GS: D15536M, D176390, D176801, D176812, D176823, D20590D, D20591E, D20592F, D21580F, D21586L, D21587M, D21588N, D21589O, D21590H

TD: D141311, D15532I, D15533J, D15534K, D15535L, D15536M, D176390, D17640T, D176801, D176812, D176823, D19598G, D20590D, D20591E, D20592F, D21579M, D21580F, D21581G, D21582H, D21583I, D21584J, D21585K, D21586L, D21587M, D21588N, D21589O, D21590H, D21591I, D21592J, D21593K

T0566

CS: D10410P, D10410P, D14264D

TC: D14264D, D14334A

GS: D14264D

TD: D10410P, D13636H, D13638J, D13848R, D13849S, D13850L, D13851M, D13852N, D13853O, D14264D, D14334A, D14709L, D14710E

T0567

CS: D15413C

TC: D15409G, D20597K

GS: D15407E, D154109, D15411A, D15413C, D17226J, D17227K, D17228L, D17229M, D20595I, D20598L, D20599M

TD: D154007, D15407E, D15408F, D15409G, D15411A, D15412B, D17226J, D17227K, D17228L, D17229M, D20595I, D20596J, D20597K, D20598L, D20599M

T0568

TC: D15340C, D17133F

GS: D15340C

TD: D15340C, D15419I, D15420B, D17133F, D17225I

T0569

TC: D14276H

GS: D140603, D14276H

TD: D132387, D14059A, D140603, D140614, D14276H, D143033, D18451U

T0570

TD: D16446P, D16447Q, D16448R, D16449S, D17079Q, D171006

T0571

CS: D17603O, D17604P, D17606R, D17607S, D18766A, D19414T, D194461, D19781D, D19782E

TC: D18766A, D20940F, D22442A

GS: D19782E

TD: D123626, D17603O, D17604P, D17606R, D17607S, D18766A, D19414T, D194461, D19781D, D19782E, D20843F, D20940F, D21449D, D21459F, D22442A

T0572

GS: D15350E, D18447Y, D184490

TD: D15350E, D157942, D18444V, D18445W, D18446X, D18447Y, D18448Z, D184490

T0573

CS: D14656P

TC: D14656P

GS: D14656P

TD: D14656P

T0574

CS: D15136A, D18228P

TC: D18016F, D18227O, D203645, D20916F, D20918H, D20921C, D21941K

GS: D12989Z, D13015U, D15136A, D18016F, D18227O, D203634, D203656, D20909G, D20912B, D20914D, D20915E, D20916F, D20918H, D20921C, D20922D, D20928J

TD: D12989Z, D12990S, D13011Q, D13012R, D13013S, D13014T, D13015U, D15136A, D15137B, D15138C, D18016F, D18017G, D18221I, D18222J, D18223K, D18224L, D18225M, D18226N, D18227O, D18228P, D18229Q, D203634, D203645, D203656, D20909G, D209109, D20911A, D20912B, D20913C, D20914D, D20915E, D20916F, D20917G, D20918H, D20919I, D20920B, D20921C, D20922D, D20923E, D20925G, D20926H, D20927I, D20928J, D21941K

T0575

TC: D15497W, D17471U

GS: D15497W, D17462T, D17471U

TD: D131475, D15497W, D15498X, D15567T, D17462T, D17471U

T0576

GS: D16310A

TD: D16309H, D16310A

T0577

TC: D15389T, D15390M, D15481O

GS: D15481O, D15514G

TD: D15388S, D15389T, D15390M, D15481O, D15514G

T0578

GS: D160305, D16244H, D163008, D18019I, D18021C, D18022D, D18023E, D20674G

TD: D160305, D16244H, D163008, D18018H, D18019I, D18020B, D18021C, D18022D, D18023E, D200680, D20674G

T0579

TC: D10325T

GS: D10325T

TD: D10325T, D14449K

T0580

TC: D13883U, D15507H

GS: D15507H, D15508I, D15509J

TD: D13488N, D13883U, D15507H, D15508I, D15509J

T0581

GS: D13686R, D13687S

TD: D13347B, D13685Q, D13686R, D13687S, D13688T, D13689U, D13690N, D13691O, D13956U, D14246B, D14515D, D14516E, D14517F

T0582

GS: D15641M

TD: D10754A, D136209, D14349H, D15641M

T0583

TC: D150458

GS: D14603C, D14604D

TD: D14602B, D14603C, D14604D, D150458, D17141F, D20317Y

T0584

TC: D16628T

GS: D16628T

TD: D16628T

T0585

CS: D15504E, D169395

TC: D15503D, D15504E, D15505F

GS: D15504E, D15506G, D16940Y

TD: D123626, D15503D, D15504E, D15505F, D15506G, D169395, D16940Y, D22442A, D22443B

T0586

TC: D13486L, D14487Q, D17151H, D206304

GS: D116358, D132252, D13486L, D14487Q, D20116R

TD: D116358, D132252, D13486L, D14487Q, D15091E, D17151H, D18343R, D18366Y, D186747, D20116R, D20117S, D20557C, D206304, D21042U

T0587

TC: D132230

GS: D132230, D16340G

TD: D13222Z, D132230, D16340G

T0588

TC: D17139L, D18428V

GS: D16682Z, D166830, D17139L, D18620T, D19106K, D20063V

TD: D16681Y, D16682Z, D166830, D17139L, D17140E, D18350Q, D18428V, D18429W, D18617Y, D18618Z, D18620T, D19106K, D20063V, D20120N, D20121O, D20122P, D20123Q, D20124R, D20125S

T0589

TC: D17699C, D17700O
TD: D17699C, D17700O, D186656

T0590

TC: D17270N
GS: D17270N, D17271O, D17272P
TD: D17270N, D17273Q

T0591

TD: D13965V, D141366

T0592

TC: D14489S, D18119L, D19241Q
GS: D132161, D13485K, D138970, D14489S, D18119L, D18120E, D19241Q
TD: D132161, D13485K, D138970, D14489S, D14653M, D15048B, D18119L, D18120E, D19241Q

T0593

TD: D16396W

T0594

TC: D18248T, D186838, D19019M
GS: D130610, D186849
TD: D103968, D130610, D13606B, D140727, D14189J, D151144, D18248T, D186827, D186838, D186849, D19019M

T0595

CS: D15266J
TC: D10048R, D14012V
GS: D12633A, D12634B, D15255G, D15257I, D15266J, D15270F
TD: D12633A, D12634B, D13429C, D15255G, D15257I, D15266J, D15270F

T0596

GS: D167662, D167684
TD: D167662, D167673, D167684

T0597

TD: D160236, D160247

T0598

GS: D10702Y, D13936Q, D14210Z

TD: D10702Y, D13936Q, D14156A, D14210Z

T0599

CS: D10763B, D12781L, D14098H, D188709, D188709

TC: D10141N, D12781L, D16906W, D188709, D21594L

GS: D12781L, D185540, D185551, D187182, D18766A, D188709, D21594L

TD: D10141N, D10763B, D111988, D12781L, D12950K, D14098H, D16325H, D16907X, D185540, D185551, D187182, D18766A, D188709, D19943D, D20213R, D206348, D21269B, D21594L

T0600

TC: D18156Q

GS: D15342E, D18156Q, D20798R, D20836G

TD: D15342E, D15343F, D18156Q, D20796P, D20797Q, D20798R, D20836G

T0601

TC: D16068J, D18882D, D203689, D20369A, D203703, D203714, D203725, D203736, D203747, D206111, D206224, D206246, D20628A, D20629B, D206304

GS: D16067I, D203689, D20369A, D203703, D203714, D203725, D203736, D203747, D206075, D206097, D206100, D206122, D206133, D206144, D206155, D206188, D206199, D206246, D20628A, D20629B, D213354

TD: D12048Z, D12778Q, D13222Z, D132230, D16066H, D16067I, D16068J, D16078L, D16079M, D16080F, D176958, D181991, D18272T, D18300G, D18301H, D18303J, D18383Z, D188232, D18882D, D19274Z, D19444Z, D19576A, D19887M, D200895, D20333Y, D203350, D203689, D20369A, D203703, D203714, D203725, D203736, D203747, D20377A, D206064, D206075, D206097, D206100, D206111, D206122, D206133, D206144, D206155, D206177, D206188, D206199, D206202, D206213, D206224, D206246, D20628A, D20629B, D213354, D21554D, D21555E

T0602

TC: D10398A

GS: D10398A

TD: D10398A

T0603

TC: D17716W

GS: D17716W

TD: D17716W

T0604

No references

T0605

GS: D14543H

Complete bibliographic citations for these references can be found on the CDROM that accompanies the book. The following abbreviations are used throughout the references: **CS** = cost summaries; **TC** = technology costs; **GS** = general studies; **TD** = technology descriptions.

TD: D106514, D14543H

T0606

TC: D120661, D17085O, D177600, D20756H

GS: D10845C, D12221U, D123353, D17084N, D17902W, D17903X, D20222S, D20893P, D20894Q

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T0607

CS: D177815, D177815, D19710Y, D19711Z, D197120, D197131, D19747B

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TD: D10845C, D112630, D112641, D112663, D112710, D112732, D112743, D112776, D11789P, D118014, D11874L, D11884N, D122190, D12220T, D12234Z, D122769, D12289E, D123513, D125304, D12674J, D131431, D133313, D13893W, D14524E, D14542G, D15487U, D16205A, D16206B, D16207C, D16208D, D16209E, D162107, D162118, D162129, D16213A, D16214B, D16215C, D16216D, D16361L, D16482T, D16536Q, D16537R, D16538S, D16539T, D177815, D17904Y, D17905Z, D18231K, D18232L, D18236P, D18237Q, D18238R, D18239S, D18241M, D18242N, D18249U, D18278Z, D18281U, D18402L, D186510, D186678, D187637, D187648, D18784C, D18872B, D18873C, D18899M, D19014H, D19072R, D19113J, D19114K, D19115L, D19116M, D19117N, D19172U, D19173V, D19176Y, D19310M, D19313P, D19360W, D19427Y, D194494, D194676, D194745, D194756, D194767, D194778, D194789, D19479A, D194847, D196434, D19710Y, D19711Z, D197120, D197131, D197426, D197437, D197448, D197459, D19746A, D19747B, D19796K, D198247, D20041P, D20136V, D20137W, D20213R, D20219X, D20220Q, D20222S, D20223T, D20240U, D20241V, D20242W, D20243X, D20244Y, D20322V, D20331W, D20401T, D205334, D20588J, D206315, D20665F, D207125, D20756H, D20817D, D20818E, D20842E, D20897T, D20904B, D20975Q, D21482E, D21486I, D21906H

T0608

TC: D11887Q, D120661, D177815, D193957

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T0609

TC: D13016V, D18278Z, D18767B, D20756H

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T0610

CS: D118069, D12303V, D170138

TC: D11809C, D194676, D195362, D21224Y, D21349A, D21947Q, D21948R

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TD: D118069, D11807A, D11808B, D11809C, D12303V, D15475Q, D19002D, D19083U, D194676, D195362, D196070, D21224Y, D21349A, D21947Q, D21948R, D221614

T0611

TC: D22454E, D22456G

GS: D108032, D13435A, D16526O, D18113F, D19577B, D224124, D22456G

TD: D108032, D13435A, D16523L, D16524M, D16525N, D16526O, D16527P, D16528Q, D18113F, D19577B, D19943D, D21016S, D21032S, D224124, D22454E, D22455F, D22456G, D22458I, D22460C

T0612

TD: D11598K, D11599L

T0613

TC: D104585, D11008N, D115424, D115479, D115515, D116154, D11871I, D12014P, D15319F, D18248T

GS: D104585, D11008N, D111740, D11549B, D11558C, D11559D, D11757H, D12032R, D12033S, D12597N, D152158, D15319F

TD: D10028N, D103560, D104585, D11008N, D11549B, D11558C, D11757H, D11871I, D12013O, D12014P, D12032R, D12033S, D12034T, D12597N, D13042X, D130610, D14002T, D14003U, D14004V, D14006X, D14105Z, D152158, D15318E, D15319F, D15426H, D15668X, D18248T

T0614

CS: D13896Z

TC: D21214W

GS: D11673E, D13509B, D135115, D19074T, D19077W, D21214W

TD: D11673E, D131453, D131839, D135115, D13896Z, D151202, D151213, D151224, D151235, D151257, D151268, D19073S, D19074T, D19075U, D19076V, D19077W, D19515X, D21214W

T0615

GS: D16635S

TD: D14120Y, D14761P, D16634R, D16635S

T0616

TC: D150141

GS: D150232, D16635S

TD: D13113V, D13766Q, D150141, D150210, D150232, D15830P, D16633Q, D16634R, D16635S, D16717T

T0617

TC: D16218F, D213161, D213172, D213194

GS: D16333H, D213150, D213161, D213183, D21320X

TD: D16217E, D16218F, D16333H, D17086P, D213150, D213161, D213172, D213183, D213194, D21320X, D21321Y

T0618

CS: D13194C
TC: D13194C, D14085C
GS: D13194C
TD: D13194C, D140829, D14083A, D14084B, D14085C, D14508E

T0619

TC: D142256
GS: D142256
TD: D142256

T0620

CS: D131533
TC: D103924, D18518W
GS: D125235, D131533, D18518W, D20105O
TD: D103924, D108043, D125235, D131533, D18518W, D20105O

T0621

GS: D15159H
TD: D15159H

T0622

TC: D20799S
GS: D15634N, D15635O, D15636P, D20799S, D20854I, D20855J
TD: D15634N, D15635O, D15636P, D20799S, D20854I, D20855J

T0623

CS: D11202N, D13873S, D14637M, D14638N, D14853S
TC: D11202N, D14637M
GS: D11202N, D14637M
TD: D11202N, D13873S, D14637M, D14638N, D14853S

T0624

TC: D20236Y
GS: D16736W, D20233V, D20234W, D20235X
TD: D166965, D166976, D16736W, D19108M, D193764, D20233V, D20234W, D20235X, D20236Y

T0625

CS: D18514S, D186769
TC: D103913, D18514S

GS: D108054, D14436F, D14440B, D15002X, D176798, D18514S

TD: D103913, D108054, D14436F, D14437G, D14440B, D15002X, D176798, D18514S, D186769, D19079Y, D19943D, D20878Q, D20882M

T0626

TC: D16094L

GS: D16094L

TD: D16092J, D16094L

T0627

CS: D10233Q, D10238V, D13427A, D18857C

GS: D10233Q, D113440

TD: D10233Q, D10238V, D10240P, D10241Q, D10872F, D10875I, D109148, D109159, D11029S, D11072V, D113440, D18857C

T0628

TD: D16439Q

T0629

TC: D10848F

GS: D10847E, D145017, D14671O

TD: D10847E, D10848F, D145017, D14671O, D15457O

T0630

TC: D14881W, D150414

GS: D14880V, D14881W, D150414

TD: D148792, D14880V, D14881W, D14882X, D150414, D150425

T0631

CS: D13776S

TC: D13776S, D18881C

GS: D13776S, D16901R

TD: D10495A, D11211O, D13529F, D13536E, D13776S, D15375N, D16901R, D18881C

T0632

TC: D10895M

GS: D12003M

TD: D10895M, D11008N, D12003M, D121551, D128029, D130610, D134032, D13468J, D14724K, D14729P, D16274N, D16663W

T0633

TC: D14695W

GS: D14693U, D14695W, D14724K, D14729P, D17142G, D17143H, D17144I

TD: D14693U, D14694V, D14695W, D14724K, D14728O, D14729P, D14730I, D15063A

T0634

TD: D16817W

T0635

TD: D16740S

T0636

GS: D16243G
TD: D16177N, D16243G

T0637

TD: D16119D

T0638

TC: D103822
GS: D103822
TD: D103822, D148781

T0639

CS: D107313, D11818D, D12906G, D14786Y, D14787Z, D18722Y
TC: D18722Y
TD: D107313, D11818D, D12906G, D14787Z, D18722Y

T0640

CS: D15530G, D15531H
GS: D15530G
TD: D15530G, D15531H

T0641

Case Study: D104552, D11217U, D13943P, D19326U, D21373A
TC: D104552, D11229Y, D22449H
GS: D104552, D19326U, D196616
TD: D104552, D10699K, D11217U, D11229Y, D125268, D12691K, D12784O, D13376G, D13943P, D139791, D142405, D19326U, D196616, D21303W, D21373A, D22449H

T0642

GS: D131544, D131555
TD: D131544, D131555

T0643

TC: D103811
GS: D14442D
TD: D103811, D13395J, D13396K, D14441C, D14442D, D14443E, D14444F, D14445G

T0644

CS: D106343, D106398, D121573, D121573

TC: D121573, D169588

GS: D106343, D106398, D121573

TD: D106343, D106387, D106398, D10772C, D121573, D135013, D135024, D13872R, D140909, D142110, D169599

T0645

TC: D12901B

GS: D103800, D108076

TD: D103800, D108076, D12901B

T0646

TC: D17132E, D188094

GS: D131679, D132445, D17132E, D18203G, D188094, D19244T, D19246V

TD: D131679, D132445, D13494L, D13737L, D149751, D149784, D14980Y, D17132E, D18203G, D188094, D19244T, D19246V, D19272X

T0647

TC: D149795, D149875, D17884B

GS: D149875, D17885C, D17887E, D199068, D199126, D20072W, D201978

TD: D132445, D13494L, D13707F, D13708G, D13709H, D13710A, D13738M, D13739N, D149762, D149795, D14981Z, D149853, D149875, D17884B, D17885C, D17886D, D17887E, D17991D, D18086T, D192681, D199057, D199068, D199079, D19908A, D19909B, D199104, D199115, D20072W, D201785, D201796, D20180Z, D201810, D201832, D201843, D201978

T0648

TD: D16615O, D16617Q, D16618R, D16619S

T0649

CS: D18864B, D18866D, D189075, D19522W

TC: D18866D, D19522W, D200691, D203816, D212828, D21287D, D21289F, D21482E, D22019Z

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T0650

CS: D12996Y, D17815Y

TC: D12995X, D13582K, D13584M, D13823I, D14008Z

GS: D12995X, D12997Z, D13582K, D13584M, D140090, D17816Z, D17820V

TD: D118105, D118116, D12996Y, D12997Z, D13582K, D13583L, D13585N, D13586O, D13587P, D13588Q, D13823I, D14518G, D17815Y, D17816Z, D178170, D178181, D178192, D17820V, D178716, D178727, D18305L, D18326Q

T0651

TD: D16804R

T0652

TC: D16802P
GS: D16802P
TD: D16802P, D16803Q

T0653

CS: D18069S, D18070L
TC: D20019R, D20493D
GS: D18066P, D18068R, D18070L, D20019R, D20493D
TD: D11645A, D11975P, D17805W, D18065O, D18066P, D18068R, D18069S, D18070L, D18071M, D18072N, D19588E, D19589F, D195908, D20019R, D20020K, D20021L, D20022M, D20023N, D20024O, D20491B, D20492C, D20493D, D214288

T0654

CS: D179377, D18093S
TC: D15758Y, D17146K, D179377, D18093S
GS: D14473K, D15758Y, D17146K, D175591, D179377, D18093S, D20979U, D21035V
TD: D130712, D14473K, D15758Y, D17146K, D17188U, D17189V, D175591, D179366, D179377, D18093S, D18346U, D18347V, D189315, D20979U, D21035V, D21390B

T0655

CS: D14472J, D14473K, D17146K, D17146K, D17146K, D17146K, D17189V, D175591, D189315
TC: D14472J, D17146K, D17189V
GS: D14472J, D14473K, D14474L, D14475M, D14476N, D17146K, D17189V, D175591, D20979U
TD: D130701, D130712, D14472J, D14473K, D14474L, D14475M, D17146K, D17188U, D17189V, D189315, D20979U, D21390B

T0656

TC: D14634J
GS: D14635K
TD: D14590O, D14634J, D14635K

T0657

TC: D225047, D225058
GS: D16814T, D225047, D225058, D225069
TD: D16812R, D16813S, D16814T, D168610, D168621, D225047, D225058, D225069, D22507A, D22508B, D22509C

T0658

TC: D11301P, D15904Q
GS: D10051M, D104450, D106547, D11301P, D12483E, D12485G, D12486H, D13912I, D15904Q, D167640
TD: D10051M, D10488B, D106547, D11301P, D113597, D12483E, D12485G, D12486H, D125279, D13912I, D13972U, D14296L, D15904Q, D167640

T0659

CS: D10058T

TC: D10058T, D12566G, D13798Y, D158898, D15906S, D199319, D22276E

GS: D10058T, D103684, D107200, D12562C, D12566G, D13715F, D13796W, D13798Y, D13799Z, D13801C, D13802D, D13927P, D158898, D158967, D158989, D15906S, D199308, D199319, D22276E

TD: D10058T, D103684, D104698, D107200, D11243W, D11845G, D12562C, D12564E, D12565F, D12566G, D12567H, D13279G, D135126, D13715F, D13795V, D13796W, D13797X, D13798Y, D13799Z, D13800B, D13802D, D13905J, D13927P, D14290F, D158898, D158967, D158989, D15906S, D197277, D19868J, D199308, D199319, D19932A, D19933B, D19934C, D201865, D20539A, D21302V, D22276E, D224088

T0660

CS: D104585, D112561, D11757H, D142121, D221658

TC: D104585, D18248T, D185835

GS: D104585, D11549B, D11558C, D11757H, D12032R, D12033S, D16978C, D186474, D221658

TD: D103673, D104585, D107357, D112550, D112561, D11549B, D11558C, D11601Y, D116187, D11757H, D12032R, D12033S, D12034T, D121391, D12231W, D13184A, D142121, D16976A, D16977B, D16978C, D16979D, D169806, D176583, D18248T, D185835, D186474, D19758E, D21225Z, D21498M, D22107Y, D22124Z, D221658

T0661

TC: D15442H, D16192M, D16278R

GS: D107368, D12813C, D13060Z, D130836

TD: D11431Y, D12813C, D12818H, D130814, D130836, D13992Y, D14093C, D142245, D15442H, D15900M, D16190K, D16191L, D16192M, D16277Q, D16488Z

T0662

TC: D17073K

TD: D17072J, D17073K

T0663

TC: D19165V

GS: D19165V, D19231O

TD: D19165V, D19231O

T0664

CS: D11254Z, D11908E, D120581, D12063Y, D12122S, D12123T, D12124U, D18426T, D20300P

TC: D11254Z, D120570, D120581, D18426T, D20300P, D20825D, D221647

GS: D10793H, D11254Z, D120570, D120581, D12071Y, D120785, D12121R, D18426T

TD: D10793H, D11253Y, D11254Z, D11908E, D120570, D120581, D12071Y, D12072Z, D120730, D120741, D120752, D120785, D120796, D12080Z, D120887, D12121R, D12143X, D16998G, D18324O, D18371V, D18425S, D18426T, D18945B, D20300P, D20670C, D20825D, D221636, D221647

T0665

TC: D12030P

TD: D12030P, D12792O

T0666

CS: D12956Q, D12959T, D13101R

GS: D12959T, D13101R, D14165B

TD: D12030P, D12143X, D12954O, D12955P, D12956Q, D12957R, D12959T, D12960M, D13101R, D14165B

T0667

CS: D13682N, D14485O

TC: D103662, D13684P, D14485O

GS: D13682N, D13684P, D14485O, D19307R, D19308S

TD: D103662, D13682N, D13683O, D13684P, D14485O, D19307R, D19308S, D19329X

T0668

TC: D12813C, D13060Z

GS: D107368, D12813C, D12818H, D13060Z, D130814, D130836, D134236, D142052

TD: D107368, D12813C, D12964Q, D13060Z, D130814, D130825, D130836, D134236, D142052, D18992I, D197277, D20057X, D20058Y, D20059Z

T0669

TC: D20476C, D20477D, D20479F, D204808, D204819

GS: D204739, D20476C, D20477D, D204808, D204819, D20482A, D22461D, D22464G, D22465H

TD: D204739, D20474A, D20475B, D20476C, D20477D, D20478E, D20479F, D204808, D204819, D20482A, D205334, D212704, D22461D, D22462E, D22464G, D22465H

T0670

CS: D13748O, D169384

TC: D169384

GS: D13748O, D13874T, D14464J, D14466L

TD: D133368, D13748O, D13874T, D13875U, D13876V, D13877W, D13878X, D138890, D13890T, D14464J, D14465K, D14466L, D14467M, D14519H, D169384

T0671

Case Study: D10513V, D105497, D105555, D127208

TC: D10513V

GS: D105555, D106616, D12714A, D12716C, D12717D

TD: D10513V, D105497, D105555, D106616, D127128, D12714A, D12716C, D12717D, D127208, D13481G

T0672

TC: D127128

GS: D127139

TD: D127128, D127139

T0673

TC: D15372K

GS: D14711F, D14716K, D14717L, D15372K, D15374M

TD: D14711F, D14716K, D14717L, D15372K, D15374M, D16488Z

T0674

CS: D104610, D104610, D104701, D107528, D11790I, D12573F, D12574G, D12575H, D12576I, D12577J, D14100U, D150527

TC: D104610, D107528, D12576I

GS: D103651, D104610, D107528, D11790I, D12577J, D150527

TD: D103651, D104610, D104701, D107528, D11790I, D12573F, D12574G, D12575H, D12576I, D12577J, D12746I, D12988Y, D13903H, D13914K, D141504, D150527

T0675

CS: D115377, D14746Q, D184672

TC: D115377, D130723, D184672, D21498M

GS: D115377, D130723, D14746Q, D21496K, D21497L, D21498M, D21499N

TD: D115377, D130723, D14746Q, D184672, D21496K, D21497L, D21498M, D21499N

T0676

CS: D177280

TC: D220600

GS: D17727Z, D177280, D207089, D220575, D220600, D220611, D220622, D220779

TD: D17725X, D17726Y, D17727Z, D177280, D207089, D220575, D220586, D220597, D220600, D220611, D220622, D220779

T0677

GS: D106252, D106263, D12101N, D12751F, D141220

TD: D106230, D106241, D106252, D106263, D12101N, D12751F, D141220

T0678

CS: D14262B, D14678V

TC: D103786

GS: D14262B, D14678V

TD: D103786, D140716, D14262B, D14448J, D14678V

T0679

TD: D15765X

T0680

TC: D103775

GS: D103775

TD: D103775, D15171D

T0681

GS: D12625A

TD: D12625A, D16375R

T0682

TC: D123819, D13192A

GS: D11205Q, D12383B, D12824F, D12845K, D19935D, D19938G, D19939H, D19944E

TD: D10794I, D11205Q, D123524, D123819, D12383B, D12824F, D12845K, D130494, D131624, D13492J, D135002, D135068, D140385, D14253A, D14577R, D19935D, D19936E, D19937F, D19938G, D19939H, D19940A, D19941B, D19942C, D19943D, D19944E

T0683

CS: D11637A, D12881O, D131395, D15516I, D15517J, D176470

TC: D12881O, D131395, D15517J, D15518K

GS: D13480F, D15516I, D15545N, D176470

TD: D11637A, D12881O, D131395, D13480F, D15444J, D15515H, D15517J, D15518K, D15519L, D15545N, D176470

T0684

CS: D14835Q

TC: D14835Q

GS: D14833O, D14834P, D14835Q

TD: D14833O, D14834P, D14835Q

T0685

TC: D14782U

GS: D14779Z

TD: D14778Y, D14779Z, D14780S, D14781T, D14782U, D14783V

T0686

TC: D14750M

GS: D14750M

TD: D14750M, D14751N, D14752O

T0687

GS: D16590W, D16592Y

TD: D16590W, D16591X, D16592Y

T0688

TC: D14839U, D14840N

TD: D14838T, D14839U, D14840N

T0689

CS: D10055Q, D12652D, D12654F

TC: D10055Q

GS: D10055Q

TD: D10055Q, D107379, D12596M, D12652D, D12653E, D12654F, D12656H, D12657I, D197277, D212271

T0690

CS: D10055Q, D125213, D12654F, D135079

TC: D10055Q, D10336W, D194723

GS: D10055Q, D10336W, D125213, D225025

TD: D10055Q, D10336W, D125213, D12654F, D12656H, D12657I, D12875Q, D135079, D15328G, D179300, D188152, D194723, D20042Q, D20043R, D20107Q, D225025

T0691

TC: D10335V, D225025

GS: D10335V, D12873O, D12874P, D188163, D225025

TD: D10055Q, D10335V, D12596M, D12654F, D12873O, D12874P, D15642N, D179300, D188163, D20107Q, D225025

T0692

GS: D178294, D22087B

TD: D178294, D178512, D220848, D22086A, D22087B

T0693

TC: D17891A

GS: D17821W, D17822X, D17830X, D17891A, D17892B, D22078A, D22079B, D220826, D220859, D22086A, D22087B

TD: D17821W, D17822X, D17830X, D17891A, D17892B, D18615W, D22078A, D22079B, D220804, D220815, D220826, D220837, D220848, D220859, D22086A, D22087B, D22088C

T0694

TD: D16108A, D16109B, D16162G

T0695

TC: D192921

GS: D192921

TD: D132161, D13485K, D138970, D14489S, D14653M, D189100, D189111, D189122, D189133, D189144, D189155, D192921

T0696

CS: D14004V, D14005W, D14006X, D17092N, D18248T, D19601U, D210491

TC: D12887U, D18248T, D19601U, D210491

GS: D14002T, D14005W, D17093O, D17094P, D17123D

TD: D115526, D115606, D115617, D12037W, D12887U, D12888V, D12889W, D12890P, D12891Q, D13042X, D14002T, D14003U, D14004V, D14005W, D14006X, D17093O, D17094P, D17123D, D18248T, D19601U, D210491

T0697

TC: D131748

GS: D131748
TD: D131748, D15633M

T0698

TC: D10319V, D15292L, D15377P, D17028F
GS: D13774Q, D15291K, D15376O, D16744W
TD: D10319V, D13561F, D13744K, D13745L, D13774Q, D14488R, D15291K, D15293M, D15294N, D15299S, D153004, D15376O, D15377P, D16744W, D17028F, D17029G, D18441S

T0699

TC: D10334U
GS: D10334U, D11932E
TD: D10334U, D11932E, D15196M, D18349X

T0700

TC: D10333T, D126249
GS: D10333T, D12625A, D12626B, D12855M, D14007Y
TD: D10333T, D126249, D12625A, D12855M, D13649M, D14007Y

T0701

TC: D19009K, D19754A, D19996Q, D20002I, D20009P, D20067Z
GS: D10332S, D126169, D12931H, D12934K, D12935L, D17031A, D19009K, D19755B, D20001H
TD: D10332S, D126169, D12929N, D12930G, D12931H, D12932I, D12933J, D12934K, D12935L, D12936M, D130461, D13563H, D14188I, D17031A, D18248T, D19009K, D19754A, D19755B, D19996Q, D19997R, D19998S, D19999T, D20000G, D20001H, D20002I, D20003J, D20004K, D20005L, D20006M, D20007N, D20008O, D20009P, D20067Z, D225014, D225036

T0702

TC: D15607K
GS: D15606J, D15607K
TD: D123546, D12668L, D13392G, D13660H, D13781P, D13783R, D13784S, D13785T, D15606J, D15607K

T0703

CS: D13775R, D13831I, D13895Y, D14284H, D14382I, D183986, D18999P, D20679L
TC: D14284H
GS: D13616D, D136209, D13831I, D13922K, D13926O, D14284H, D15245E, D183986, D18999P, D20681F, D20682G
TD: D10260T, D12043U, D12668L, D13009W, D133415, D13390E, D13616D, D136209, D13621A, D13775R, D13831I, D13895Y, D13922K, D13926O, D14284H, D14285I, D14382I, D15245E, D183986, D18999P, D20679L, D20680E, D20681F, D20682G, D20683H

Complete bibliographic citations for these references can be found on the CDROM that accompanies the book. The following abbreviations are used throughout the references: **CS** = cost summaries; **TC** = technology costs; **GS** = general studies; **TD** = technology descriptions.

T0704

CS: D11873K, D12666J, D12667K

TC: D112867, D17470T

GS: D12010L, D12666J, D131704, D17176Q, D17178S, D17470T, D19026L, D20556B, D20559E, D205607

TD: D10260T, D112867, D11580A, D11582C, D11873K, D12010L, D12042T, D12666J, D12667K, D12668L, D12669M, D131704, D13616D, D17175P, D17176Q, D17177R, D17178S, D17470T, D19026L, D20556B, D20557C, D20558D, D20559E, D205607, D205618, D20677J

T0705

TC: D12618B

GS: D12619C, D21241Z

TD: D12618B, D12619C, D21241Z

T0706

CS: D13717H, D14194G

TC: D126205, D126216, D126227, D14194G, D14687W

GS: D14193F, D14194G, D14687W, D16909Z, D21241Z

TD: D10331R, D126205, D126216, D126227, D126238, D12882P, D13036Z, D13717H, D14193F, D14194G, D14195H, D14687W, D16909Z, D16910S, D21241Z

T0707

GS: D16377T

TD: D16377T, D16409K

T0708

TC: D177371

GS: D177393

TD: D177371, D177382, D177393

T0709

CS: D15656T, D15657U, D15657U, D21396H, D220939

TC: D15657U, D15712K, D17813W, D21483F, D220939

GS: D15656T, D15657U, D15659W, D15712K, D21483F

TD: D10796K, D15654R, D15655S, D15656T, D15657U, D15659W, D15712K, D158741, D17813W, D17814X, D20237Z, D21396H, D21483F, D21946P, D220906, D220939

T0710

GS: D151199

TD: D133448, D151166, D151199, D167720

T0711

CS: D14299O, D143000, D143000, D14358I, D14359J, D14359J

TC: D14358I, D14359J

GS: D14299O, D143000, D14358I, D14359J

TD: D141526, D14299O, D143000, D14318A, D14319B, D143204, D14358I, D14359J

T0712

CS: D10330Q, D12745H, D19966K

TC: D10225Q, D10330Q, D12529B, D12776O, D19966K

GS: D10225Q, D12528A, D12745H

TD: D10225Q, D10330Q, D119006, D12489K, D12528A, D12538C, D125439, D12745H, D12776O, D13901F, D198076, D19943D, D19967L, D19968M

T0713

CS: D16660T, D16661U, D166841, D17252L, D17253M, D17259S

TC: D109308, D16334I, D18976I

GS: D16334I, D16660T, D16661U, D166841, D17253M, D17259S

TD: D109308, D16334I, D166590, D16660T, D16661U, D166841, D17253M, D18976I

T0714

TC: D10190W

GS: D10190W

TD: D10190W

T0715

CS: D10739B, D10956I, D10956I, D124389, D14110W, D150527, D15845W

TC: D10956I, D14110W, D21038Y, D212340

GS: D10956I, D124378, D15845W, D21038Y, D212340

TD: D101882, D10739B, D10956I, D124378, D124389, D127059, D14110W, D150527, D15845W, D197277, D19934C, D21038Y, D212340

T0716

CS: D106569, D11826D

GS: D11826D

TD: D106569, D11826D

T0717

CS: D10443Y, D107404, D107404, D12494H, D12832F, D12833G, D17023A, D17023A, D194869

TC: D12494H, D17023A, D194869

GS: D107404, D132707

TD: D10443Y, D107404, D12490D, D12494H, D12832F, D12833G, D13268D, D13269E, D132707, D139995, D14111X, D14113Z, D141162, D142063, D170218, D170229, D17023A, D194869

T0718

TD: D11878P, D15653Q

T0719

TC: D10200H, D11242V

GS: D10200H, D11242V, D11962K

TD: D10200H, D10258Z, D11242V, D11585F, D11954K, D11962K, D13908M, D14121Z, D150516, D16142C

T0720

TD: D16824V

T0721

CS: D14934S

GS: D14934S

TD: D10865G, D14934S

T0722

GS: D16455Q

TD: D16455Q, D16456R, D16457S

T0723

TD: D16246J

T0724

TC: D10328W

GS: D10328W

TD: D10328W, D16248L, D16249M

T0725

CS: D13951P, D14901J, D14902K, D14903L, D14904M

GS: D13951P, D14901J, D14902K, D14903L, D14904M

TD: D13951P, D14901J, D14902K, D14903L, D14904M

T0726

TC: D13766Q, D141468, D150141, D16486X

GS: D16635S

TD: D115424, D13113V, D13544E, D13749P, D13763N, D13766Q, D13908M, D141195, D141468, D143157, D150141, D150163, D150196, D150221, D15433G, D15436J, D15830P, D15880Z, D158843, D158934, D158945, D158956, D15899A, D16485W, D16486X, D16633Q, D16634R, D16635S

T0727

TC: D213241

GS: D107415, D213241

TD: D107415, D141413, D142234, D15740O, D15741P, D197277, D19868J, D201865, D213241

T0728

TD: D160316

T0729

TC: D15421C
GS: D10326U
TD: D10326U, D15383N, D15384O

T0730

CS: D176710, D176721
TC: D15306A, D15307B, D176710
GS: D10798M, D15306A, D176710, D176732, D18711V
TD: D10798M, D15306A, D15307B, D15308C, D15541J, D176710, D176732, D176878, D18596A, D18711V

T0731

TD: D17078P

T0732

Case Study: D10058T, D10183X, D105453, D10695G, D13120U, D132627, D13906K, D15434H, D17249Q, D17261M
TC: D11243W
GS: D13906K, D15434H
TD: D10001C, D103684, D105431, D105442, D10698J, D11046T, D11243W, D11828F, D127048, D141708, D14277I, D15271G, D16147H, D16148I, D17250J

T0733

CS: D11659G, D14360C, D14912M, D17223G, D19001C
TC: D11659G, D14360C
GS: D107426, D134429, D14360C, D17223G
TD: D107426, D11659G, D134429, D14360C, D14911L, D14912M, D17217I, D17223G, D19001C

T0734

CS: D13197F, D13773P, D15324C
TC: D15324C
GS: D13197F, D153208, D153219
TD: D13197F, D135308, D13651G, D13663K, D13773P, D153219, D15322A, D15324C

T0735

CS: D132467, D132478
TC: D132478
GS: D132467, D133528
TD: D132467, D132478, D13296H, D133528

T0736

CS: D16567X, D16569Z, D16570S

GS: D16562S, D16563T, D16564U, D16567X, D16570S, D17480V

TD: D16443M, D16560Q, D16562S, D16563T, D16564U, D16567X, D16568Y, D16569Z, D16570S, D17480V

T0737

TC: D18205I

GS: D16806T, D16823U, D18203G, D18204H, D18205I, D18435U, D19246V, D192590, D194472

TD: D16801O, D16806T, D16807U, D16808V, D16809W, D16810P, D16820R, D16821S, D16822T, D16823U, D16831U, D16832V, D16833W, D18201E, D18202F, D18203G, D18204H, D18205I, D18434T, D18435U, D19246V, D19249Y, D19257Y, D19258Z, D192590, D194472

T0738

TC: D17920Y, D199148

GS: D13169B, D179184, D179195, D17921Z, D19008J, D22298K, D224066

TD: D13169B, D15362I, D15363J, D15364K, D15365L, D179173, D179184, D179195, D17920Y, D17921Z, D179264, D18613U, D19008J, D19112I, D199148, D22298K, D22299L, D22300X, D224011, D224022, D224033, D224044, D224055, D224066

T0739

TC: D148770, D17050D

GS: D10323R, D148770

TD: D10323R, D148770

T0740

GS: D15463M, D15466P

TD: D15463M, D15464N, D15465O, D15466P, D15467Q

T0741

TC: D12759N, D12762I

GS: D12759N, D12760G

TD: D12759N, D12760G, D12761H, D12762I

T0742

TC: D169497

GS: D16914W, D169486, D169497, D169500

TD: D102932, D123535, D12382A, D124505, D124516, D124527, D12651C, D12898X, D12899Y, D130494, D15287O, D15474P, D158887, D160087, D160098, D16355N, D16914W, D169486, D169497, D169500

T0743

TC: D202937

GS: D18085S, D18086T, D19899Q, D202391

TD: D16393T, D16394U, D16395V, D18083Q, D18084R, D18085S, D18086T, D19899Q, D202391, D202915, D202926, D202937

T0744

TD: D133379, D15325D, D15326E, D15327F, D16912U

T0745

TC: D19128Q, D19129R, D19413S
GS: D19132M, D19133N, D194450
TD: D19128Q, D19129R, D19132M, D19133N, D19134O, D19135P, D19413S, D194450

T0746

CS: D10246V, D10246V, D107437, D11132Q, D113382, D113382, D113393
TC: D10246V, D113382
GS: D10246V, D11334Y, D11335Z, D113382
TD: D10246V, D10514W, D107437, D11132Q, D11333X, D11334Y, D11335Z, D113360, D113371, D113382, D11340W, D11341X, D114603, D197277, D205367, D21396H

T0747

CS: D10688H, D120978
TC: D114523, D118149, D198076
GS: D10688H, D112823, D114523, D120956, D120978, D122292, D12230V, D12233Y, D122543, D12285A, D185620, D18880B, D221738
TD: D10688H, D112812, D112823, D11316W, D114523, D120752, D120934, D120945, D120956, D120978, D12197B, D12207W, D122292, D12230V, D12233Y, D122543, D122849, D12285A, D12286B, D12288D, D18430P, D18431Q, D185620, D18713X, D18880B, D197277, D198076, D22100R, D221669, D22167A, D22168B, D22169C, D221705, D221716, D221738, D221818

T0748

CS: D11316W, D114523, D120956, D12233Y, D122543, D122554, D140705, D141275, D168698, D17601M, D18431Q, D18433S, D18785D, D18879I, D18880B, D18884F, D19010D, D19237U, D19262V, D19319V, D194530, D19516Y, D20026Q, D20026Q, D20039V, D200920, D200986, D20100J, D20100J, D20101K, D20102L, D20103M, D20104N, D20106P, D20109S, D20110L, D20112N, D20116R, D20117S
TC: D11318Y, D114523, D118149, D168698, D18785D, D19319V, D19516Y, D20027R, D20039V, D200986, D20102L, D20105O
GS: D10688H, D114523, D12233Y, D122543, D122554, D140705, D141275, D168698, D18431Q, D18432R, D18877G, D18883E, D18884F, D189199, D19262V, D200986, D200997, D20111M, D20113O, D20116R
TD: D10688H, D112823, D11316W, D11317X, D11318Y, D11319Z, D11320S, D114512, D114523, D120752, D12197B, D122281, D12233Y, D122543, D140705, D141275, D168698, D17601M, D18365X, D18430P, D18431Q, D18432R, D18433S, D18434T, D18785D, D18880B, D18884F, D19319V, D194530, D19516Y, D20026Q, D20027R, D20028S, D200975, D200986, D200997, D20101K, D20103M, D20105O, D20106P, D20109S, D20117S

T0749

CS: D120956, D18431Q, D18433S, D18785D, D18879I, D18880B, D18884F, D19237U, D194530, D19516Y, D20026Q, D20039V, D200920, D200986, D20100J, D20101K, D20103M, D20109S, D20110L, D20112N, D20116R, D20117S
TC: D175977, D17601M, D18431Q, D18785D, D19516Y, D20038U, D20039V, D200986, D20109S

GS: D120956, D18877G, D18879I, D18883E, D18884F, D189199, D19262V, D200920, D200997, D20109S, D20111M, D20113O, D20116R

TD: D120956, D175977, D175988, D17600L, D17601M, D17602N, D18431Q, D18785D, D18793D, D18794E, D18877G, D18878H, D18879I, D18880B, D18884F, D194530, D19516Y, D20027R, D20039V, D200920, D200986, D200997, D20100J, D20101K, D20109S, D20111M, D20116R, D20117S

T0750

TC: D18882D

GS: D14810H, D16636T

TD: D14809O, D14810H, D14811I, D15473O, D16636T, D16637U, D16638V, D18025G, D18026H

T0751

GS: D11881K, D142529, D14949Z, D14952U, D17949B, D179504, D17993F, D20213R

TD: D11881K, D13652H, D14942S, D14949Z, D14950S, D14951T, D14952U, D14953V, D14954W, D17949B, D179504, D17993F, D17994G, D20211P, D20212Q, D20213R

T0752

TC: D10322Q, D18248T

GS: D10322Q, D14739R, D14741L, D14742M, D20301Q, D20302R, D20303S

TD: D10322Q, D14738Q, D14739R, D14740K, D14741L, D14742M, D14858X, D18248T, D20301Q, D20302R, D20303S

T0753

TD: D111795, D115559, D11755F, D11756G, D11868N, D11976Q, D11987T, D12019U

T0754

GS: D17080J

TD: D16915X, D17091M, D18714Y

T0755

CS: D14669U

TC: D14667S

GS: D122689, D13788W, D13827M, D140589, D14666R, D14667S, D14669U, D152114, D15701H

TD: D12036V, D122689, D133131, D13437C, D13788W, D13827M, D140589, D14666R, D14667S, D14669U, D152114, D15701H, D15702I, D15703J, D15704K, D15705L, D15706M, D15710I

T0756

TC: D11868N, D11985R, D17156M

TD: D106161, D111795, D115548, D115559, D115628, D11565B, D115708, D11742A, D11750A, D11751B, D11755F, D11756G, D11760C, D11867M, D11868N, D11945J, D11973N, D11975P, D11976Q, D11977R, D11985R, D11987T, D11991P, D11992Q, D12019U, D12060V, D120810, D120821, D120832, D121686, D121700, D12196A, D125224, D134338, D13993Z, D14565N, D167877, D17155L, D17156M, D17157N, D17158O, D17159P, D17160I, D18081O, D18441S, D189224

T0757

CS: D11782I, D12463A, D12592I, D13508A, D193684, D19848F, D19849G, D198509, D19853C, D19854D

TC: D12463A, D193684, D19849G

GS: D10015I, D12463A, D13508A, D193684, D19847E, D19848F, D19849G, D198509, D19851A, D19854D

TD: D10200H, D11782I, D11962K, D12463A, D12592I, D13508A, D15750Q, D18219O, D18220H, D193684, D19844B, D19846D, D19848F, D19849G, D198509, D19852B, D19853C, D19854D

T0758

CS: D189097

TC: D189097

GS: D189097

TD: D189086, D189097

T0759

CS: D14934S, D14936U, D16071E

TC: D16070D, D16071E

GS: D14934S, D14936U, D16071E

TD: D11386A, D12742E, D13470D, D13495M, D14927T, D14928U, D14929V, D14933R, D14934S, D14935T, D14936U, D14938W, D14941R, D14943T, D14944U, D14945V, D14946W, D15249I, D15250B, D15252D, D15404B, D15578W, D15910O, D16070D, D16071E, D16153F, D17241I, D17242J, D17243K

T0760

CS: D10321P, D14452F, D18153N

TC: D14453G

GS: D10321P, D12278B, D14452F, D14720G, D18153N

TD: D10321P, D12278B, D143408, D14452F, D14453G, D14720G, D18153N

T0761

CS: D14650J, D17047I, D17047I

TC: D14650J

GS: D14650J, D17047I

TD: D10320O, D14650J

T0762

CS: D14669U

TC: D14667S

GS: D14666R, D14667S, D14669U

TD: D14666R, D14667S, D14669U

T0763

CS: D17636X, D17637Y, D196412

TC: D17631S

GS: D17632T, D17635W, D17636X, D17637Y, D183840, D196412

TD: D17631S, D17632T, D17633U, D17634V, D17635W, D17636X, D17637Y, D17638Z, D183840, D196412

T0764

CS: D13097C, D14686V

TC: D10180U

GS: D13097C, D14686V

TD: D13097C, D14395N, D14686V

T0765

TD: D10337X

T0766

TC: D20637B, D20937K

GS: D166943, D166954, D171108, D18207K, D20637B, D20937K

TD: D166943, D166954, D17109F, D171108, D18207K, D20637B, D20638C, D20639D, D206406, D20858M, D20937K, D21207X, D22447F

T0767

TC: D16027A

GS: D16027A

TD: D10799N, D16027A, D16028B, D16029C

T0768

CS: D10061O

TC: D10061O, D12501Z

GS: D10061O, D10140M

TD: D10061O, D10140M, D12501Z, D125020, D13491I, D17601M, D13771N, D13772O

T0769

TC: D168290, D21392D

GS: D16828Z, D168290, D21392D

TD: D16828Z, D168290, D18374Y, D20587I, D21392D

T0770

CS: D16546S, D16546S, D16546S

TC: D16546S

GS: D16546S, D16550O

TD: D16546S, D16547T, D16548U, D16549V, D16550O, D19520U

T0771

TC: D168596

TD: D13538G, D13829O, D168596

T0772

TC: D15817S
GS: D10090T, D126045, D189508
TD: D10090T, D126045, D15817S, D187262, D189508

T0773

TC: D100890, D121631
GS: D121631, D121653
TD: D100890, D121631, D121653, D121664

T0774

TC: D10342U
GS: D10342U, D116369, D15066D, D15067E, D15097K, D18948E, D18949F, D189508
TD: D10342U, D116369, D15066D, D15067E, D18948E, D18949F, D189508, D18960A

T0775

CS: D126409, D12726E, D18271S, D18949F
TC: D125053, D12730A, D13945R, D18517V
GS: D125053, D126409, D12726E, D12731B, D18271S, D18517V, D18946C, D18948E, D18949F, D189508
TD: D116369, D125053, D126409, D12724C, D12725D, D12726E, D12730A, D12731B, D12782M, D13945R, D15841S, D18271S, D18517V, D18946C, D18948E, D18949F, D189508, D18965F

T0776

CS: D169759
TC: D10341T, D18517V, D21575I, D21576J
GS: D10341T, D12676L, D15067E, D169759, D18517V, D18948E, D18949F
TD: D10341T, D12676L, D14348G, D15067E, D15361H, D169759, D183691, D18517V, D18948E, D18949F, D18961B, D21575I, D21576J

T0777

TC: D10339Z, D20737E
GS: D12782M, D15348K, D15349L, D18948E, D18949F, D213332
TD: D10339Z, D12782M, D15348K, D15349L, D18721X, D18759B, D18946C, D18948E, D18949F, D189508, D18963D, D20737E, D207409, D213332

T0778

CS: D14588U
TC: D10343V
GS: D13886X, D14588U
TD: D10343V, D125053, D12822D, D13712C, D13886X, D14587T, D14588U, D18946C, D18964E

T0779

CS: D107459, D125031, D12629E, D12828J, D12828J, D13944Q, D15840R
TC: D125031, D12629E, D12828J, D18517V, D22449H

GS: D125031, D125053, D12629E, D126409, D12828J, D15840R, D18517V, D18949F, D19868J, D20237Z

TD: D104778, D107459, D116369, D11914C, D125031, D125042, D125053, D12629E, D126409, D12828J, D13909N, D13945R, D14169F, D142223, D15827U, D15840R, D15843U, D18517V, D18949F, D18962C, D18966G, D19342U, D19868J, D20237Z, D21562D, D21568J, D21569K, D22449H

T0780

TC: D15838X

GS: D15067E, D18948E, D18949F

TD: D13886X, D15067E, D15354I, D15838X, D18948E, D18949F, D189508

T0781

GS: D157873

TD: D15781X, D157862, D157873

T0782

CS: D10344W, D10344W, D104712, D10511T, D107448, D12493G, D12707B, D170069, D19500Q, D197095

TC: D10344W, D12493G, D19500Q, D197095

GS: D10511T, D11845G, D170069

TD: D104712, D10511T, D107448, D12493G, D12707B, D14024Z, D146990

T0783

GS: D16566W, D16571T, D16573V, D17247O, D17260L

TD: D16565V, D16566W, D16571T, D16573V, D16639W, D16640P, D17247O, D17248P, D17260L, D177440, D183873

T0784

CS: D14256D, D14257E, D15047A, D18105F

TC: D14256D, D142609, D18515T, D21457D

GS: D14256D, D14257E, D14258F, D18098X, D21053X, D21462A

TD: D14023Y, D140567, D140578, D14254B, D14256D, D14257E, D14258F, D142609, D14261A, D15047A, D18094T, D18095U, D18096V, D18098X, D18099Y, D18100A, D18104E, D18105F, D18106G, D18107H, D18109J, D18110C, D18181R, D18515T, D185711, D18954C, D19335V, D20330V, D21053X, D214506, D21455B, D21457D, D21462A

T0785

TC: D142609, D18515T, D21457D

GS: D18098X, D18100A, D18106G, D18107H, D18181R, D185711, D196398, D21053X, D21462A

TD: D14254B, D14257E, D14258F, D142609, D15047A, D15451I, D18094T, D18098X, D18100A, D18104E, D18106G, D18107H, D18109J, D18110C, D18181R, D18515T, D185711, D18954C, D19335V, D196398, D20330V, D21053X, D214506, D21455B, D21457D, D21462A

T0786

TD: D103560, D15668X, D15669Y

T0787

Case Study: D10958K, D11663C

TC: D10958K, D170207, D199013, D19926C, D19928E

GS: D10345X, D10958K, D12585J, D12744G, D17018D, D170207, D199024, D19926C, D19927D, D19928E

TD: D10345X, D104847, D10746A, D10958K, D11663C, D11762E, D12744G, D14681Q, D17017C, D17018D, D17019E, D170207, D197277, D199013, D199035, D199046, D19926C, D19929F

T0788

GS: D12160Y, D166670

TD: D12160Y, D166670, D166681

T0789

GS: D10273Y, D15720K, D16090H

TD: D10273Y, D15716O, D15720K, D158912, D16089O, D16090H, D16091I

T0790

TC: D162209

GS: D16219G, D162209, D16269Q, D18606V

TD: D16219G, D162209, D16269Q, D16270J, D18606V

T0791

TC: D13741H

GS: D13741H

TD: D10077W, D13741H

T0792

CS: D14680P, D171017, D171017

TC: D14680P, D171017

GS: D14655O, D14680P, D171028, D171039

TD: D14655O, D14680P, D154018, D171028, D171039, D17104A, D17105B, D17106C, D17107D, D17108E

T0793

TC: D160112

GS: D160123

TD: D15855Y, D160112, D160123

T0794

CS: D10503T, D10688H, D107346, D10739B, D10956I, D11316W, D114523, D116518, D120978, D12233Y, D122543, D122554, D13717H, D140705, D141275, D14194G, D14269I, D14270B, D14568Q, D14593R, D14594S, D150527, D15845W, D158774, D168698, D19010D, D19319V, D19666B, D20026Q, D20081X, D20100J, D20102L, D20104N, D20106P

TC: D10949J, D12529B, D131340, D141140, D15673U, D168698, D18515T, D19025K, D194858, D19487A, D19666B, D19667C, D20081X, D20082Y, D216002

GS: D10325T, D10503T, D10949J, D10956I, D116518, D131340, D141140, D14194G, D14257E, D14269I, D14568Q, D15673U, D168698, D18105F, D18515T, D194858, D19487A, D19666B, D19667C, D20081X, D20082Y, D216002, D21902D

TD: D10009K, D10013G, D10077W, D101871, D10225Q, D102761, D102965, D10302M, D10324S, D10325T, D10351V, D10370Y, D103800, D10398A, D10409W, D10415U, D10503T, D106230, D106241, D106252, D106263, D108076, D10949J, D10956I, D11316W, D116518, D11770E, D119006, D11924E, D12101N, D124378, D12529B, D12538C, D12697Q, D12698R, D12699S, D12706A, D12751F, D12872N, D12901B, D12902C, D130621, D13097C, D131282, D131340, D131384, D132514, D13498P, D13740G, D13741H, D13858T, D13942O, D140567, D140578, D141140, D141220, D14194G, D142096, D142165, D14254B, D14256D, D14257E, D14258F, D142609, D14269I, D14270B, D14271C, D14281E, D14395N, D14449K, D14454H, D14456J, D14567P, D14568Q, D14569R, D14570K, D14591P, D14593R, D14594S, D14595T, D14598W, D14610B, D14611C, D14612D, D14613E, D14614F, D14686V, D14692T, D14732K, D14733L, D15003Y, D150050, D150061, D150072, D150469, D15047A, D150505, D15057C, D15092F, D15100Y, D151020, D151042, D152012, D152147, D15385P, D15386Q, D15387R, D15652P, D15673U, D15676X, D15677Y, D15680T, D158774, D158956, D15908U, D160305, D160349, D16244H, D16576Y, D168698, D18105F, D18375Z, D18515T, D19025K, D194858, D19487A, D19499E, D19666B, D19667C, D19797L, D20026Q, D20081X, D20082Y, D203270, D203281, D20547A, D21554D, D216002, D21901C, D21902D, D21903E, D21904F, D21905G

T0795

CS: D125097, D125122, D16923X

TC: D12104Q, D125097, D125122, D18550W, D21558H

GS: D114534, D125075, D125097, D125100, D125111, D125122, D16923X, D17740W, D18515T, D18550W, D21558H

TD: D10347Z, D103480, D114534, D12104Q, D125075, D125097, D125100, D125111, D125122, D12920E, D13554G, D16923X, D17740W, D18515T, D18550W, D189359, D19007I, D19247W, D20237Z, D21557G, D21558H, D21559I, D21560B, D21561C, D21564F, D21570D

T0796

CS: D133186, D13555H

TC: D13375F, D21036W, D212351

GS: D108065, D133186, D13555H, D13556I, D13557J, D21036W, D212351

TD: D103877, D108065, D12896V, D132616, D133186, D13529F, D13555H, D13556I, D13557J, D21036W, D212351

T0797

GS: D12384C

TD: D12384C, D12771J, D12830D, D12834H

T0798

TC: D20116R, D21040S, D21230W, D21231X, D21232Y, D21233Z, D21574H

GS: D16268P, D16298V, D192761, D19853C, D20070U, D20117S, D21040S, D21230W, D21231X, D21232Y, D21233Z, D21572F, D21573G, D21574H

TD: D106649, D16154G, D16267O, D16268P, D16298V, D192761, D19853C, D20070U, D20116R, D20117S, D21016S, D21030Q, D21040S, D21230W, D21231X, D21232Y, D21233Z, D21572F, D21573G, D21574H

T0799

CS: D14372G

TC: D13938S

GS: D13711B, D13719J, D138981, D14372G, D16997F

TD: D103491, D13711B, D13719J, D13722E, D138981, D13938S, D14372G, D16997F, D18609Y

T0800

TC: D19769H, D202380

GS: D18936A, D18938C, D19103H, D19765D, D20237Z, D202380

TD: D11985R, D18936A, D18937B, D18938C, D18939D, D19103H, D19107L, D19765D, D19767F, D19768G, D19769H, D20237Z, D202380

T0801

TC: D150141

TD: D14761P, D150141, D16299W, D16633Q, D16634R, D16635S, D167695

T0802

CS: D12969V, D12972Q, D16183L, D16304C

TC: D103731, D18304K

GS: D12969V, D16183L, D16185N, D16304C, D18304K, D198145

TD: D103731, D12968U, D12969V, D16183L, D16276P, D16304C, D18304K

T0803

TC: D10371Z

GS: D10371Z

TD: D10371Z, D15176I

T0804

TC: D103720

GS: D103720

TD: D103720, D10702Y, D13770M, D13772O, D158683, D187284, D188152, D193877, D193888

T0805

TC: D10370Y, D12902C

GS: D10370Y, D12902C

TD: D10370Y, D12902C

T0806

TC: D10350U

Complete bibliographic citations for these references can be found on the CDROM that accompanies the book. The following abbreviations are used throughout the references: **CS** = cost summaries; **TC** = technology costs; **GS** = general studies; **TD** = technology descriptions.

GS: D10350U

TD: D10350U, D13842L, D13843M, D13844N, D13845O, D13846P, D13961R, D18157R, D18158S

T0807

TC: D140738

GS: D140738, D15816R

TD: D140738, D15816R

T0808

CS: D14862T, D14868Z

TC: D14867Y, D18248T

GS: D14862T, D14866X, D14868Z, D18078T, D20297B

TD: D14862T, D14863U, D14864V, D14866X, D14867Y, D14868Z, D148690, D18074P, D18076R, D18078T, D18248T, D20297B, D20298C

T0809

CS: D10059U, D104869, D13391F

TC: D10059U

GS: D10059U, D104869

TD: D10059U, D104687, D104869, D10747B, D11574C, D11958O, D12831E, D13391F

T0810

CS: D14076B, D141333, D14185F

TC: D14185F, D14263C

GS: D14263C

TD: D11962K, D14076B, D141333, D14185F, D14263C

T0811

TC: D10351V

GS: D10351V

TD: D10351V

T0812

CS: D149999, D17015A, D17015A, D18246R

TC: D149966

GS: D149999, D15000V, D15001W, D17015A, D18246R

TD: D114181, D149955, D149966, D149977, D149988, D15443I, D18246R, D187273, D18787F, D18792C

T0813

TD: D13993Z, D139951, D140421, D14201Y, D14925R, D15450H, D158876, D16171H, D16172I, D16324G

T0814

TD: D141402, D142278, D14514C, D15825S, D158978, D16186O, D16187P, D16188Q, D16189R, D16324G

T0815

GS: D11875M
TD: D11875M, D16095M, D16096N, D16097O, D16098P

T0816

TD: D140272, D15512E, D15713L, D157964

T0817

CS: D15099M, D15367N, D18461W
TC: D15099M, D15367N, D18461W
GS: D15099M
TD: D13293E, D13714E, D15098L, D15099M, D15367N, D18461W, D21500Z, D21551A

T0818

TC: D10352W
GS: D10352W, D15174G, D15175H, D16292P
TD: D10352W, D15174G, D15175H, D16292P

T0819

TC: D16174K, D16175L, D20141S, D20575E
GS: D16175L, D16240D, D18081O, D20568F, D20569G, D20572B
TD: D16174K, D16175L, D16176M, D16240D, D16241E, D16242F, D18081O, D193491, D205629, D20563A, D20564B, D20565C, D20566D, D20567E, D20568F, D20569G, D205709, D20571A, D20572B, D20573C, D20574D, D20575E, D20576F

T0820

CS: D18543X
TC: D18543X
GS: D161104, D18543X
TD: D161104, D18543X

T0821

TC: D107277, D168552
GS: D10052N, D104461, D107277, D125519, D12552A, D12692L, D142041, D168552
TD: D10052N, D104461, D107277, D125508, D125519, D12552A, D12692L, D142041, D143339, D168552, D168563

T0822

CS: D107255, D203849, D20385A, D20386B
TC: D15520E, D15525J, D188243, D20225V, D20226W
GS: D107255, D10885K, D15520E, D15525J, D17812V, D20226W, D20231T
TD: D107255, D10885K, D134203, D13436B, D13956U, D14481K, D15520E, D15521F, D15522G, D15523H, D15524I, D15525J, D15526K, D15527L, D15528M, D158901, D17812V, D188243, D197277,

D20224U, D20225V, D20226W, D20227X, D20228Y, D20229Z, D20230S, D20231T, D20232U, D203838, D203849, D20385A, D20386B

T0823

CS: D10060N, D13354A

TC: D10060N

GS: D10060N, D104472, D12648H

TD: D10060N, D104472, D10754A, D12647G, D13008V, D13010P, D13381D, D13499Q

T0824

TC: D16630N

GS: D16630N

TD: D10784G, D16629U, D16630N, D16631O, D16632P

T0825

TC: D160269, D176914, D213616

GS: D130767, D158730, D176914, D213616

TD: D130767, D158730, D160258, D160269, D176914, D19224P, D213616

T0826

CS: D12871M, D12871M, D12871M, D15901N, D17036F, D19954G, D19954G, D19957J

TC: D12857O, D17036F, D19756C, D19947H, D19952E, D19955H

GS: D10785H, D12857O, D12871M, D12973R, D13908M, D152034, D15901N, D17036F, D17037G, D19946G, D19947H, D19948I, D19949J, D19950C, D19952E, D19953F, D19954G, D19955H, D19958K

TD: D10785H, D11022L, D125406, D125417, D125428, D12857O, D12871M, D12973R, D13908M, D152034, D15901N, D17036F, D17037G, D19757D, D19945F, D19947H, D19948I, D19949J, D19950C, D19951D, D19953F, D19954G, D19955H, D19956I, D19957J

T0827

TC: D15559T

GS: D15493S, D15495U, D15558S, D15559T

TD: D125428, D15493S, D15495U, D15554O, D15555P, D15556Q, D15558S, D15559T, D15560M, D18441S

T0828

TD: D13358E, D13362A, D167957

T0829

TC: D204579, D204615, D204637

GS: D204568, D204579, D204604, D204637

TD: D204568, D204579, D20458A, D20459B, D204604, D204615, D204626, D204637, D20734B, D20735C

T0830

CS: D14800F, D15458P
TC: D14800F
GS: D14800F, D15391N, D15458P
TD: D14800F, D15391N, D15392O, D15393P, D15394Q, D15395R, D15396S, D15458P, D15460J

T0831

GS: D15670R, D15671S
TD: D15670R, D15671S

T0832

TC: D12985V, D12986W, D17995H, D17996I
GS: D12985V, D17120A
TD: D12985V, D12986W, D17120A, D17995H, D17996I, D18302I

T0833

CS: D123626, D12366A, D12368C, D124629, D12636D, D13629I, D141300, D162016, D162027
TC: D123626, D13629I, D162016, D18881C
GS: D123626, D141300, D142267, D16194O, D162016
TD: D114341, D124629, D139940, D14168E, D154029, D162005, D162016

T0834

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TC: D123626, D12366A, D124629, D13629I, D17222F, D19079Y, D205505
GS: D123626, D12366A, D124629, D127037, D12708C, D130767, D13113V, D14157B, D14538K, D158854, D17221E, D19079Y, D20056W, D205505, D21491F
TD: D10424V, D10748C, D123626, D123648, D123659, D12366A, D12367B, D12368C, D124629, D125133, D12635C, D12636D, D127037, D12708C, D12793P, D130767, D13113V, D13629I, D13917N, D14157B, D14538K, D158854, D17221E, D17222F, D19079Y, D20056W, D205505, D21304X, D21491F

T0835

GS: D141355, D15643O
TD: D141355, D15643O

T0836

TD: D16223C, D16224D

T0837

TD: D17807Y, D17894D

T0838

CS: D16462P

TC: D21950L

GS: D16462P, D16464R, D16465S, D16466T, D18679C, D21950L

TD: D16461O, D16462P, D16463Q, D16464R, D16465S, D16466T, D168938, D168949, D16895A, D18677A, D18678B, D18679C, D21950L, D22050Y

T0839

TC: D19338Y, D19792G, D213296

GS: D16372O, D16374Q, D18513R, D19338Y, D19791F, D213285

TD: D16371N, D16372O, D16373P, D16374Q, D18513R, D19338Y, D19790E, D19791F, D19792G, D213274, D213285, D213296

T0840

CS: D131715

GS: D131715, D131726, D131737

TD: D10863E, D131715, D131726, D131737, D14749T

T0841

GS: D151075, D151086

TD: D151064, D151075, D151086, D151097

T0842

GS: D16541N, D16543P

TD: D16541N, D16542O, D16543P, D16545R, D17076N, D17077O

T0843

TD: D13303Z, D13806H

T0844

GS: D14744O

TD: D14743N, D14744O

T0845

TC: D117317, D15604H

TD: D10665A, D117317, D14291G, D14470H, D15602F, D15603G, D15604H

T0846

GS: D18059Q, D18060J

TD: D18059Q, D18060J

T0847

TD: D15476R, D167844

T0848

GS: D111933, D16222B
TD: D111933, D16222B

T0849

GS: D15609M
TD: D15575T, D15609M, D15610F

T0850

TC: D19431U
GS: D14446H, D15612H, D19889O, D19893K, D19894L, D19896N, D19897O, D19899Q, D199002
TD: D112878, D14446H, D14447I, D14719N, D15612H, D18447Y, D18620T, D19233Q, D193491, D19425W, D198203, D19889O, D19890H, D19891I, D19892J, D19893K, D19894L, D19895M, D19896N, D19897O, D19898P, D19899Q, D199002

T0851

GS: D15613I, D15615K
TD: D14447I, D15613I, D15615K, D15616L, D15626N

T0852

CS: D10056R, D107266, D131191
TC: D10056R
GS: D10056R, D131191
TD: D10056R, D107266, D11242V, D131191, D14088F, D150516, D16297U

T0853

TC: D16035A, D18881C, D224306
TD: D10496B, D10502S, D16035A, D16036B, D18345T, D18441S, D21014Q, D22429D, D224306, D224317

T0854

TC: D14408B
TD: D10353X, D144058, D14408B

T0855

TC: D10048R, D10940A, D13550C, D13551D, D14012V
GS: D14478P, D15262F
TD: D10940A, D11203O, D132649, D13429C, D13553F, D14202Z, D14478P, D15253E, D15254F, D15256H, D15257I, D15258J, D15260D, D15262F, D15264H, D15266J, D17215G

T0856

TD: D16763Z

T0857

TC: D10402P
GS: D10402P
TD: D10402P

T0858

GS: D12315Z, D13542C
TD: D12315Z, D13542C, D15647S

T0859

TC: D15571P
GS: D15490P, D15571P, D15662R
TD: D15490P, D15492R, D15571P, D15572Q, D15573R, D15574S, D15608L

T0860

TC: D15502C
GS: D15501B
TD: D15501B, D15502C, D15546O, D17186S, D17187T

T0861

TC: D15628P
GS: D15628P
TD: D15177J, D15628P

T0862

TC: D13902G, D17204D, D17472V, D18248T, D205301
GS: D10782E, D13168A, D135228, D135239, D13524A, D17201A, D17202B, D17204D, D17456V, D17467Y, D17472V, D18248T, D205312, D205323
TD: D10355Z, D10598G, D10782E, D111999, D13168A, D135228, D135239, D13524A, D13854P, D13902G, D143044, D143328, D15427I, D15430D, D17201A, D17202B, D17203C, D17204D, D17456V, D17467Y, D17472V, D18248T, D205287, D205298, D205301, D205312, D205323

T0863

TC: D148850
GS: D14892Z
TD: D13117Z, D148850, D14892Z

T0864

TC: D15372K
GS: D15372K, D15374M
TD: D15372K, D15374M

T0865

CS: D12945N, D12946O, D13879Y, D14099I, D188709, D188709

TC: D12946O, D14099I, D188709
GS: D12945N, D12946O, D13879Y, D188709
TD: D11888R, D12945N, D12946O, D13879Y, D188709

T0866

GS: D166783, D166794, D197277, D22459J
TD: D108098, D166783, D166794, D16680X, D16896B, D197277, D22458I, D22459J, D22460C, D22471F

T0867

TD: D16500E, D16501F

T0868

CS: D107346, D116518, D158774, D19666B
TC: D12698R, D19666B
GS: D116518, D12697Q, D12698R, D158774
TD: D116518, D11770E, D12697Q, D12698R, D12699S, D12706A, D13498P, D13914K, D150527, D158774, D19666B, D19934C, D201865

T0869

GS: D15739V
TD: D15738U, D15739V

T0870

TC: D103593
GS: D103593, D157953
TD: D103593, D157953, D16581V

T0871

CS: D12664H
GS: D107517, D12664H, D12665I
TD: D107517, D12664H, D12665I, D14196I, D14247C

T0872

TC: D10318U
GS: D10318U
TD: D10318U

T0873

TC: D13109Z, D13117Z, D148861, D14891Y
GS: D13110S, D131180
TD: D13109Z, D13110S, D13117Z, D131180, D13389L, D148894

T0874

GS: D16584Y, D165860
TD: D16583X, D16584Y, D16585Z, D165860

T0875

CS: D151199
GS: D151166, D151199, D185391, D197153, D197164
TD: D14182C, D151166, D151199, D19370Y, D197164

T0876

TD: D178534, D178545, D189519

T0877

CS: D115628, D11756G, D11868N, D12064Z, D121697
TC: D11868N
GS: D11742A, D11868N, D11976Q, D12064Z, D121700, D18974G, D18975H
TD: D115559, D115628, D11742A, D11755F, D11756G, D11760C, D11867M, D11868N, D11869O, D11976Q, D11985R, D11987T, D121700, D18974G, D18975H

T0878

Case Study: D17646Z
GS: D140261, D17646Z
TD: D140261, D17646Z, D22453D, D22457H, D22472G, D22473H

T0879

GS: D16745X, D16747Z
TD: D16745X, D16747Z, D16897C

T0880

TC: D157851
TD: D10599H, D157840, D157851

T0881

CS: D14391J, D14391J, D14392K, D14393L, D18516U, D18723Z, D198087, D198112
TC: D12467E, D14389P, D14391J, D18516U
GS: D14392K, D14393L, D18516U, D198112
TD: D106605, D11691G, D14388O, D14390I, D14393L, D14394M, D18516U, D18723Z, D198076, D198087, D198112

T0882

TC: D14727N

GS: D14726M, D14727N, D15195L
TD: D132263, D14030X, D14726M, D14727N, D15195L

T0883

TD: D13476J, D16551P, D16552Q

T0884

CS: D118127, D11909F, D123375, D123386, D123455, D123488, D12826H, D13811E
TC: D118127, D123455, D123477
GS: D118127, D123375, D123455, D123466, D123488, D123499, D12826H, D13811E
TD: D118127, D11909F, D123364, D123375, D123386, D123397, D123400, D123422, D123444, D123455, D12826H, D13811E, D143248, D143259, D14326A, D14327B, D18178W

T0885

CS: D132569, D141311, D15724O, D15726Q, D18179X, D188083, D19270V
TC: D15726Q, D188083, D19270V
GS: D15724O, D188083, D19270V
TD: D132569, D141311, D14462H, D15724O, D15725P, D15726Q, D17608T, D18179X, D188083, D19270V, D19353X

T0886

TC: D18900Y, D189020, D19762A, D206257, D224339
GS: D189020, D197619, D19762A, D20114P, D20116R, D206257, D224339, D22434A
TD: D18900Y, D18901Z, D189020, D19092V, D197619, D19762A, D20114P, D20115Q, D20116R, D20117S, D206257, D21295D, D224328, D224339, D22434A, D22435B, D22436C, D22437D, D22438E, D22439F

T0887

CS: D14722I, D179479, D179479
TC: D179479
GS: D132354, D14663O, D14722I, D179479
TD: D116507, D132354, D14661M, D14662N, D14663O, D14664P, D14665Q, D14722I, D14870T, D179446, D179457, D179468, D179479, D18248T, D18361T, D18427U

T0888

TC: D16657Y
TD: D115559, D11987T, D123728, D12375B, D130290, D13221Y, D13821G, D142176, D151417, D15144A, D15147D, D15399V, D15495U, D15554O, D15558S, D15559T, D15560M, D15571P, D15574S, D15608L, D16657Y

T0889

CS: D12062X, D13311Z, D169613, D188356
TC: D10863E, D11776K, D122714, D169613
GS: D10863E, D115140, D12062X, D122532, D15173F, D169613, D18526W, D186587

TD: D10863E, D11350Y, D114829, D115140, D11520Y, D11776K, D12062X, D12208X, D12209Y, D12210R, D12225Y, D122714, D123284, D12464B, D12469G, D13311Z, D13483I, D142198, D14747R, D14748S, D14965Z, D149660, D15172E, D15173F, D15449O, D169613, D169624, D169635, D169646, D169657, D169668, D169679, D16968A, D16969B, D169704, D169715, D169726, D18526W, D186587, D188323, D188334, D188345, D188356

T0890

TC: D16559X
GS: D16533N
TD: D16531L, D16533N, D16535P, D16559X

T0891

TC: D17810T
GS: D17810T
TD: D17810T

T0892

CS: D10361X, D12240X
TC: D10361X
GS: D10361X
TD: D10361X, D12240X

T0893

TC: D10415U, D15057C
GS: D10415U, D15100Y, D20138X
TD: D10415U, D15057C, D15092F, D15100Y, D20138X

T0894

TC: D21566H
GS: D10755B, D111944, D15822P, D15837W, D160054, D177542, D194541
TD: D10755B, D111944, D15822P, D15837W, D160054, D16898D, D177520, D177531, D177542, D194541, D197277, D21565G, D21566H, D21567I

T0895

TC: D16557V
TD: D16555T, D16557V, D16558W, D17044F, D17045G

T0896

GS: D15639S
TD: D10362Y, D103640, D13394I, D15639S, D160338

T0897

GS: D10363Z
TD: D10363Z, D13393H, D15328G

T0898

TC: D10317T, D15630J
GS: D15629Q
TD: D10317T, D15570O, D15629Q

T0899

CS: D10506W, D10757D, D13399N, D13678R
TC: D10506W, D10757D
GS: D10757D, D13678R
TD: D10506W, D10757D, D110941, D13678R, D13679S, D13680L, D13681M, D15856Z, D178669

T0900

TC: D10497C, D10507X, D13677Q
GS: D10507X, D111875, D13677Q, D14549N, D14633I
TD: D10497C, D10507X, D106627, D10756C, D111875, D11656D, D11657E, D12297E, D13677Q, D14549N, D14631G, D14633I, D197277, D20237Z

T0901

GS: D19776G, D19778I
TD: D19774E, D19775F, D19776G, D19777H, D19778I, D19779J, D19780C, D19871E

SPECIFIC CHEMICAL INDEX

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