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IN SITU BIOREMEDIATION IN EUROPE

A. Porta
J. K. Young
P. M. Molton

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IN SITU BIOREMEDIATION IN EUROPE

Augusto Porta,[a] Joan K. Young, and Peter M. Molton

ABSTRACT

Site remediation activity in Europe is increasing, even if not at the forced pace of the U.S. Although there is a better understanding of the benefits of bioremediation than of other approaches, especially about in situ bioremediation of contaminated soils, relatively few projects have been carried out full-scale in Europe or in the U.S. Some engineering companies and large industrial companies in Europe are investigating bioremediation and biotreatment technologies, in some cases to solve their internal waste problems. Technologies related to the application of microorganisms to the soil, release of nutrients into the soil, and enhancement of microbial decontamination are being tested through various additives such as surfactants, ion exchange resins, limestone, or dolomite. New equipment has been developed for crushing and mixing or injecting and sparging the microorganisms, as have new reactor technologies (e.g., rotating aerator reactors, biometal sludge reactors, and special mobile containers for simultaneous storage, transportation, and biodegradation of contaminated soil). Some work has also been done with immobilized enzymes to support and restore enzymatic activities related to partial or total xenobiotic decontamination. Finally, some major programs funded by public and private institutions confirm that increasing numbers of firms have a working interest in bioremediation.

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a) Battelle Europe, 7, route de Drize, 1227 Carouge, Geneve, Switzerland.

INTRODUCTION

This paper contains a discussion of the status of bioremediation efforts in Europe, including the status of regulations, market size, and innovative approaches, and how they might be applied in the U.S. Remediation activity in Europe is growing. Progress has been made in applying microorganisms to the soil and enhancing microbial decontamination through various additives such as surfactants, ion exchange resins, and limestone or dolomite. New equipment is available from industry for crushing or mixing the soil and injecting and sparging the microorganisms. New reactor technologies in Europe include rotating aerator reactors, biometal sludge reactors, and special mobile containers for storage, transportation, and biodegradation of contaminated soil. Some work has been done on using immobilized enzymes to support and restore enzymatic activities with regard to xenobiotic decontamination. Some major programs are now being funded either publicly or privately; but the lack of a unified regulatory framework in Europe for bioremediation activities is a serious hindrance to progress in this area.

REGULATIONS

In Europe, there is no standard methodology for classifying a contaminated site. Three regions, The Netherlands, Denmark, and Germany, have high levels of public awareness that influence sound environmental legislation. These regions and the United Kingdom have spent considerable time and money identifying hazardous waste sites.

In The Netherlands, sites are classified by soil quality guidelines. The Dutch "ABC" list addresses heavy metals, organics, and pesticides in soils, groundwater, surface water, and drinking water. In 1991, the list was updated to address soil pollutants by group. Various länders in Germany published different soil evaluation procedures in the 1980s. Due to lack of regulatory standards for soil in many other European countries, soil pollution is not officially recognized until the existence of contamination is noted in the underlying groundwater. In many remaining European countries, well-established standards will be needed to select and prioritize contaminated soil sites and remediation activities.

MARKET SIZE

Market size information is extremely tentative, because initial investigations on the degree of pollution in soils have not been completed in many European countries. The Netherlands, Germany, and Denmark have established a complete list of polluted sites. Finland, Italy, France, Norway, and Sweden have prepared only a preliminary list of sites (known or suspected). The United Kingdom has prepared such a list, but has decided not to publish it, fearing adverse effects on property values.

Estimates of the total number of sites are difficult to obtain because of the different criteria used for classification, insufficient knowledge of the extent and depth of pollution, and a perceived lack of urgency to clean up individual sites. The figures reported by different sources vary considerably, and estimation of the number of actual sites is likely to be low in several countries due to the limited knowledge about the situation.

The estimated total and yearly expenditures on remediation by country are shown in Table 1. In Germany, the largest market in Europe, the estimate ranges from $10 to 239 billion (U.S). The Netherlands is the second largest market; markets in France, Italy, and some of the Scandinavian countries are still marginal due to limited emphasis on cleanup.

Factors that will encourage market growth in Europe are public opinion, better knowledge of the state of soil pollution and what other countries are doing about it, introducing concise regulations, protecting drinking water supplies from groundwater, recognizing the necessity for preserving the integrity of limited soil resources, and developing cheap remediation technologies and in situ tools for screening analysis.

On the other side, delays in market growth will result from difficulty in identifying who is responsible for the contamination and who will assume the costs. Treatment costs are still much too high, which exacerbates the problem, especially for old sites. Finding the necessary financial resources will require that consortia, industrial associations, sectorial institutions, and private companies use financial measures such as self-taxation, mixed participation, joint ventures, and guaranteed mutual funds.

BIOREMEDIATION APPROACHES

As various pollution problems are addressed in Europe, the scope and diversity of in situ bioremediation technology continue to grow. The large projected expenditures for soil remediation in Germany, The Netherlands, and Denmark make it likely that progress will continue in bioremediation research and development. In situ bioremediation is attractive because it costs less to clean up large areas of polluted land.

Table 2 provides an overview of European organizations active in bioremediation and their major technologies. This is not a complete list. Many other countries have performed in situ bioremediation actions and been involved in full-scale demonstrations. In situ technologies being developed in Europe include biotreatment with air-stripping and various microbial treatments.

Germany

Germany has spent more time and money than any other country identifying environmental problems, and thus has the largest number of companies working on bioremediation, at 22 remediation centers (Table 3). A number of these companies are located in the former East Germany. The list of contaminated sites and needed remedial actions has been dramatically increased by German reunification. Risk sites include vehicle workshops, airports, traffic and parking areas, waste dumps, fuel storage and transfer points, and munitions sites.

According the Federal Ministry of Research and Technology (BMFT) in Germany, 28 bioremediation techniques have been applied there. BMFT has sponsored the 16 projects summarized in Table 4 with a total funding of 20 million DM ($12.5 million U.S.). The German Research Association has also conducted projects in enzymatic dehalogenation of contaminants using *Pseudomonas* and *Streptomyces* and thermophilic microorganisms, and in biodegradation for "dioxin-like" substances.

A number of companies conduct polyaromatic hydrocarbon (PAH) decontamination using microbes. De Ruiter Milieutechnologie, Halfweg, conducted a demonstration project involving aliphatic or aromatic hydrocarbons to study the influence of pH, nutrient addition (potassium, nitrate, and others), and inoculation of adapted microorganisms. The German bioremediation firm, Argus Umweltbiotechnologie GmbH, uses infiltration of air and addition of nutrients to degrade hydrocarbons in situ. The Chemisches Laboratorium E. Wessling-Altenberge blows ozone through contaminated soil to degrade PAHs.

Some innovative technologies are being developed at the Fraunhofer Institute. Research at the Department of Chemical Microbiology of the Fraunhofer Institute of Interface Technology and Biotechnology is focused on microbial and engineering aspects of bioremoval of xenobiotic compounds from wastewaters and exhausted air. In particular, they have demonstrated that PAH biodegradation can be achieved in airlift bioreactors and accelerated using water-soluble solvents as lipophilic mediators to facilitate mass transfer. The biological process in airlift reactors is carried out in an organic-aqueous mixed phase.

Wilhelm Universitat of Muenster and the Technical University of Munich studied the application of specially developed, immobilized microorganisms to xenobiotically degrade soil contamination. These immobilized microorganisms have better resistance to soil microflora, because they are affixed to a microporous support that provides a habitat promoting reproduction of microbial cells yet allowing release of cells from the support.

Work is under way in Germany to introduce nutrients into the soil using explosive cartridges. Soil-mixing machines expedite mixing the soil with ion exchange resins, dolomite or limestone (to adjust pH), and nutrients. Microorganisms and enzymes are immobilized on wood chips, granular clay, anthracite, and synthetic polymers to assist their establishment in the soil matrix. The use of earthworms to biotransform pesticides is being examined by the Institut for Bodenokologie.

The Tardecon process significantly raises the rates of decontamination by mixing activated sludge with soil contaminated with mineral oil and polycyclic hydrocarbons. The State of Baden-Württenberg is conducting a development program to evaluate new remedial techniques. An abandoned dump near Heidelberg has been selected for demonstrating in situ decontamination of the soil column using steel pipes inserted horizontally into the ground by vibration. The so-called "old site" program in the former East Germany has been set up, and more than 20 projects have been initiated using soil-venting and bioventing. With the large number of problem areas in Eastern Germany, risk assessments are under way to identify remedial measures to block pathways, lower the toxic content, and control exposure risks.

The Netherlands

The Netherlands and Denmark are leaders in establishing nationwide programs for decontaminating thousands of sites. A number of well-established companies are located in the Netherlands, and a significant number of sites have been cleaned up since 1982. Soil pollution is an environmental problem of the highest priority because of the limited land area and proximity to sea level. In situ bioreclamation is one of several methods available for treating oily wastes and PAH in sediments. Delft University of Technology has demonstrated venting-assisted evaporation of contaminants. A petroleum-contaminated site at Asten was used to evaluate the feasibility of in situ bioremediation and showed good prospects for remediation of the petroleum spill if hydrogen peroxide was added as a chemical alternative to oxygen.

A biological method for water treatment is available that uses controlled biological oxidation in sulfide reactors. A full-scale biological treatment facility that uses the Thiopaq process started in mid-1992 at Budelco BV (a zinc manufacturer). The process treats the groundwater, highly polluted with sulfate and heavy metals, underneath the property. Sulfur compounds are reduced to hydrogen sulfide using anaerobic sulfate-reducing bacteria, and heavy metals are precipitated as metal sulfides. The remaining sulfide is oxidized to elemental sulfur using aerobic sulfide-oxidizing bacteria, and elemental sulfur is then separated from the water.

TAUW Infra Konsult has developed Biopur, an innovative bioreactor for simultaneous cleanup of groundwater and soil vapor contaminated with xenobiotic compounds. Biopur is a fixed-film bioreactor filled with polyurethane as carrier material for the biomass.

Scandinavia

In Denmark, a company (Bioteknisk Jordens) treated 130,000 tons of soil by biological methods. In Finland, Alko specialized in the biological removal of chlorophenol in the soil. They have piloted the method on more than nine sites. Sweden and Norway have conducted projects on abandoned wood-treating and cokework sites.

Other Regions

Other European countries working to address contamination issues include Italy, France, the Spanish province of Catalonia, Switzerland, and the United Kingdom. These countries have made efforts to identify contaminated sites (the United Kingdom reportedly has 50,000 to 100,000 contaminated waste sites) but have not yet defined nationwide decontamination measures, selected technical approaches, or planned large decontamination projects. Meanwhile, Spain, Portugal, Greece, and Ireland are just beginning to assess contamination problems and sites to be remediated.

An interesting development in France is the use of algal cultures in aqueous solutions to stabilize cesium and strontium in the soil. These cultures are used primarily for shallow surface contamination, but adaptations may be possible to extend the technology to groundwater and subsurface contamination. Experimental programs are being conducted in collaboration with the former USSR.

The French DVM (Decontaminating Vegetal Network) process is a biomechanical method for removing soil contamination using plants that create a dense root network that traps the contaminated soil particles. Removing the turf then removes the contaminated soil. Biosurfactant-producing microorganisms have been used to increase the removal of contaminants using soil washing.

In Eastern Europe, several Czech companies offer reasonably advanced bioremediation services. A microbial mixed population is being studied by the University of Prague to treat surface contamination in an abandoned site polluted with petroleum hydrocarbons.

COMPARISON WITH U.S. BIOREMEDIATION TECHNOLOGY

The status of U.S. bioremediation technologies is briefly reviewed here for comparison purposes. Routine applications of in situ bioremediation in the U.S. are limited mostly to small-scale treatment of surface and near-surface contaminated soils and groundwater. Contaminants are degraded with native microorganisms and topical application of nutrients.

Research programs are under way to increase the capabilities of bioremediation to deep, extensive, subsurface contamination due to chlorinated hydrocarbons and complex mixed wastes, including soils and groundwater. The U.S. Environmental Protection Agency (EPA) is focusing on the waste types at 1200 National Priority List sites, including organic solvents, wood-preserving chemicals, halogenated aromatic hydrocarbons, pesticides, and munitions waste. Technology development funded by the U.S. Department of Energy (DOE) treats volatile organic compounds in both arid and nonarid soils. The DOE plans to demonstrate bioremediation technology in actual field conditions.

Injecting air into the vadose zone or aquifers (at depths below the water table) is becoming a practical alternative for subsurface soil and groundwater treatment in the U.S. Co-metabolites, nitrate, and inoculum may also be injected (in conjunction with oxygen for aerobic processes) to stimulate degradation of chlorinated organics. Horizontal wells transport gas-phase nutrients through tight soils at sufficiently low flow rates to prevent transport of volatile organics to the surface. When soils are so tightly bound that movement of oxygen and nutrients is severely restricted (as is the case in saturated zones), hydrofracturing is used to modify the soil to create transport passages. While horizontal wells for nutrient delivery are being tested at DOE sites such as Savannah River and Hanford, further engineering will be required before they can be considered reliable in situ treatment technologies. Bioremediation of contaminated sediments and sludges is in the early stages of development, and much research will be required to design viable field-scale processes.

Field tests currently being conducted by EPA include fungal treatment of pentachlorophenol (PCP), bioventing of contaminated vadose soils, and bioremediation of an aquifer contaminated with solvent. Field demonstration data will be made available through the ATTIC database for many of the tests being conducted. Treatability studies and testing protocol are currently being developed by the EPA so that the efficacy of various bioremediation strategies can be evaluated in advance. Table 5 presents some selected U.S. in situ bioremediation projects.

Recommendations

The American Academy of Microbiology (AAM) has concluded that enough knowledge is now available for field trials of bioremediation technology for organic compounds. Research is needed for the following classes of environmental pollutants: metals, metalloids, radionuclides, and complex polycyclic hydrocarbons. In all of these areas, Europe offers promising technologies.

TABLE 1. Estimated Total and Yearly Expenditures on Remediation by Country (Europe).

Country	Estimated total cost for remediation (US $)	Present yearly expenditures in relation to soil remediation (US $)
Germany	10-230 billion	3-6 billion
Denmark	~ 3.8 billion	100 million
Sweden		40 million
Italy	~ 3 billion	15-18 million
France	10.5-12.5 billion	35-70 million
The Netherlands	2.7 billion	~ 260 million
Switzerland	1.5 billion	
Other Nordic Countries		20 million
Great Britain	30 billion	60 million

TABLE 2. European Organizations Active in Bioremediation and Their Major Technologies.

Company	Location	State of Development	Soil Treatment	Ground-water Treatment	In Situ Treatment	Onsite and/or Offsite Treatment
Germany						
Gertec GmbH - Vieehoferstrasse	Essen					
Trautmann GmbH - Aktienstrasse	Essen					
HP Biotechnologie GmbH - Witten	Witten					
Trischler GmbH - Darmstadt	Darmstadt	Demonstration projects	X		X	X
Caro Biotechnik - Aachen	Aachen					
Hochtief AG - Essen	Essen	Laboratory & industrial scale	X		X	X
Messer Griesheim GmbH - Krefeld	Krefeld	Test field completed	X		X	
Xenex Gesellschaft zur biotechnischen Schadstoffsanierung	Iserlohn		X		X	
TGU Technologieberatung Grundwasser und Umwelt GmbH	Koblenz	Field tests	X	X	X	

Company	Location	State of Development	Soil Treatment	Ground-water Treatment	In Situ Treatment	Onsite and/or Offsite Treatment
Santec GmbH - Berlin	Berlin	Pilot test	X		X	
BCE - Koblenz	Koblenz					
EBI - Karlsruhe	Karlsruhe					
Argus Umweltbiotechnologie GmbH	Berlin	Industrial-scale demonstration	X		X	X
IBL - Heidelberg	Heidelberg					
Umweltschutz Nord - Ganderkesee	Ganderkesee	Full-scale demonstration projects	X	X	X	X
Fraunhofer Institut für Grenzflächen und Bioverfahranstechnik (FIIGB) - Stuttgart	Stuttgart	Pilot tests	X			
Gesselschaft für Boden und Grundwassersanierung mbH - Kirchheim/Tech	Kirchheim/ Tech					
GBF Gesellschaft für Biotechnologische Forschung mbH - Braunschweig	Braun- schweig		X		X	
Degussa AG - Hanau	Hanau	Research at laboratory	X		X	
Institut für Technische Chemie Lehrstul 11 - TU - München		München				

Company	Location	State of Development	Soil Treatment	Ground-water Treatment	In Situ Treatment	Onsite and/or Offsite Treatment
GSF Forschungszentrum für Umwelt und Gesundheit Institut für Bodenökologie	Neuherberg					
Engler Bunte Institut						
University of Karlsruhe	Karlsruhe					
Linde AG	Hollriegelstreuth	Research and field demonstration	X	X	X	X
Institute für Gewässerschutz	Kiel					
Hamburg Botanical Institute	Hamburg	Research	X			
Hamburger Wasserwerke Consulaqua	Hamburg	Full-scale demonstration	X			
Westfäüsche Wilhelms Universitat Münster	Münster	Pilot tests	X			
Institute für Mikrobiologie - Technical University, Braunschweig	Braunschweig					
Este GmbH	Hamburg	Full-scale demonstration (Shell Bioreg)	X	X		X
Herbst Umwelttechnik		Pilot scale		X		X

Company	Location	State of Development	Soil Treatment	Ground-water Treatment	In Situ Treatment	Onsite and/or Offsite Treatment
Institut für Molekularbiologie und Analytik GmbH	Zeppelin-heim	Field demonstration completed	X		X	
Groth U.CO.	Pinneberg	Full-scale demonstration	X	X		X
Senator Projekt Service GmbH	Düsseldorf	Demonstration full-scale project (GDS process)	X	X		
Kloeckner Oecotec GmbH	Duisburg	Full-scale demonstration	X	X	X	X
LFU, Labor für Umweltanalytik GmbH	Berlin	Full-scale Demonstration	X		X	
Philipp Holzmann AG	Düsseldorf	Pilot and field study (Shell Bioreg)	X	X	X	X
Rethmann Städtereinigung GmbH	Selm	Pilot project	X			X
Anakat, Institut für Biotechnologie	Berlin	Full-scale demonstration	X		X	X
Bauer Spezialtiefbau GmbH	Schroben-hausen	Full-scale demonstration	X			X

Company	Location	State of Development	Soil Treatment	Ground-water Treatment	In Situ Treatment	Onsite and/or Offsite Treatment
Biodetox Gesellschaft zur biologischen Schadstoffentsorgung GmbH	Ahnsen/b. Bückegurg	Industrial-scale	X	X	X	X
Bonnenberg & Drescher	Aldenhoven	Pilot plant	X		X	
Deutsche Shell	Hamburg	Pilot projects (Shell Bioreg)	X			X
Biolipsia GmbH	Markklee-berg					
CBA GmbH - Chemie, Biotechnologie Analytic - Sonneberg	Sonneberg					
COMCO MARTECH Deutschland GmbH	Halle					
Fichtner GmbH	Dresden					
Ign.-Büro Grünzel GmbH	Dessau					
Insitu GmbH Gessellsch. f. Boden u. Grundwasser-sanierung - Sonneberg/Thür	Sonneberg/ Thür					
Ökotec GmbH - Belzig	Belzig					
Santec GmbH - Ing.-Büro f. Sanierungs-technologien	Ketzin					

Company	Location	State of Development	Soil Treatment	Ground-water Treatment	In Situ Treatment	Onsite and/or Offsite Treatment
France						
Elf Atochem						
Institut Francais du Pétrole 92506 Rueil Malmaison Cédex	Rueil Malmaison					
A.T.E.	Meyzieu					
BRGM	Orléans					
Geoclean - Dardilly	Dardilly (Lyon)					
IBS France - Techniparc 5 - St. Michel sur Orge	St. Michel sur Orge					
Burgeap - Paris	Paris					
The Netherlands						
TAUW Infra Consult BV	Deventer	Full-scale demonstration	X	X	X	
Rijksinstituut voor Volsgezondheid en Milieuhygiene (RIVM)	Bilthoven	Cleanup on demonstration scale	X	X	X	
TNO Environment and Energy	Apeldorn	Cleanup on demonstration scale	X	X	X	

Company	Location	State of Development	Soil Treatment	Ground-water Treatment	In Situ Treatment	Onsite and/or Offsite Treatment
Ecolyse	Groningen	Small-scale demonstration	X	X	X	
Ballast Nedam Milieutechniek BV	Lekkerkerk					
Paques BV	Ab Balk	Full-scale installation		X		X
Delft Geotechnics	Delft	Experimental field project completed	X	X	X	
Ecotechniek BV	Utrecht	Research	X			X
Heidemij Reststoffendiensten BV Afdeling Milieutechniek	Waalwijk	Developed technology	X			X
Heijmans Milieutechniek BV	Rosmalen		X			X
HWZ-Milieu	Gouda	Research	X		X	
Mourik Groot-Ammers BV	Groot-Ammers	Fill-scale demonstration	X	X	X	X
De Ruiter Milieutechnologie	Halfweg and Zwanenburg	Full-scale demonstration	X		X	X
Witteveen + Bos-Consulting Engineers	Deventer	Production scale trials	X			X

Company	Location	State of Development	Soil Treatment	Groundwater Treatment	In Situ Treatment	Onsite and/or Offsite Treatment
Scandinavia						
Aquateam Norwegian Water Technology Center	Oslo, Norway	Full-scale project	X			X
Terrateam A/S	Oslo, Norway	Full-scale project	X			X
Senter for Industriforskning						
Danish Geotechnical Institute						
Bioteknisk Jordens KK Miljöteknik	Kalundborg, Denmark		X		X	X
Alko	Finland					
Neste Oil	Finland					
Skanska and Consultants	Sweden					
Banverket	Sweden					
VBB-VIAK	Sweden					
ANOX	Sweden	Pilot project	X			
FUNGINOVA	Sweden					
AGA	Sweden					
Neste Oxo	Sweden					
Abitec Ab	Sweden					

Company	Location	State of Development	Soil Treatment	Ground-water Treatment	In Situ Treatment	Onsite and/or Offsite Treatment
Other Regions						
Department of Biotechnology Institute of Microbiology and Virology	Kiev, Ukraine					
Prague Institute of Technical Chemistry, Institute of Microbiology and Biochemistry	Prague, Czech Republic					
GS Geological SErvices	Podebrady, Czech Republic					
AREA	Prague, Czech Republic					
Agricultural University	Gödöllö, Hungary					
Pyrus Environmental Services, Ltd.						
Proterra Umwelttechnik GmbH	Vienna, Austria					
Groundwater Technology Int., Ltd.	Epsom, U.K.	Industrial scale remediation	X	X	X	
Land Restoration Systems	Slough, U.K.	Experimental installation	X	X	X	X

Company	Location	State of Development	Soil Treatment	Ground-water Treatment	In Situ Treatment	Onsite and/or Offsite Treatment
Biotal	Cardiff, Wales	Development of microbial products	X	X		
DDH Désinfection/Dépolution/-Hygiéne	Saxon, Switzerland	Pilot	X		X	
Ebiox AG	Sursee, Switzerland	Full-scale projects	X	X	X	X
Optima Kosmetix	Prilly, Switzerland					
MBT Umwelstechnik AG	Zurich, Switzerland		X	X		
Universität für Bodenkultur	Vienna, Austria					

TABLE 3. Planned or Existing Remediation Centers for Offsite Remediation in Germany.

	Status		Treatment		
Location	Planned	Realized or In Use	Thermal	Physico-chemical	Biological
Hamburg-Veddel		X		X	
Hamburg-Billbrook	X			X	X
Hamburg-Elmsbüttel		X		X	
Hamburg-Peute		X		X	
Itzehoe		X		X	
Ganderkesee		X			X
Bremen		X			X
Ahnsen		X			X
Hildesheim	X		X	X	X
Northeim-Göttingen		X			X
Berlin-Gronau		X			X
Berlin-Tiergarten			X		
Grosskreuz				X	X
Münster	X				X
Hattingen	X			X	
Bochum	X				X
Duisburg	X		X		
Dresden	X			X	X
Gröben (bei Meissen)	X			X	X
Schwarze Pumpe	X		X	X	X
Neunkirchen			X	X	X
Frankfurt			X	X	X

TABLE 4. BMFT-Sponsored Bioremediation Technologies.

Sponsored Institutions	Time	DM
Stadt Hamburg	1985-1988	804,450
IWL Köln	1986-1987	58,200
Probiotec	1986-1988	331,785
Inst. für Umweltanalytik und Biotechnologie	1986-1988	438,470
TU Hamburg	1986-1992	1,064,174
TU Braunschweig	1987-1989	1,933,000
TU Göttingen	1987-1991	1,030,505
Ruhrkohle Öl und Gas GmbH	1988-1993	817,373
Biodetox	1988-1991	647,000
DMT	1988-1993	4,811,958
HDI	1988-1992	1,253,103
Land Hessen	1989-1992	2,494,042
Uni Karlsruhe	1990-1993	2,945,210
Tu Braunschweig	1990-1992	959,920
Bauer-Spezial-Tiefbau	1990-1993	20,845,804

TABLE 5. Selected In Situ Bioremediation Projects in the U.S.

Name/Location	Technology	Contaminant	Status
Allied Chemical & Ironton Coke, PA	Bioremediation of lagoon sediments	PAHs	Predesign completed in winter 1993
French Ltd, TX	In situ lagoon	VOCs, PAHs	In design
Fairfield Coal and Gas, IA	In situ sludge; injection of H_2O_2 and other nutrients	BTEX, naphthalene	Field-scale pilot test completed in January 1994.
Libby Groundwater, MT	Injection of H_2O_2 and potassium tripolyphosphate	Benzene, PCP, and creosote	Operational
Kelly AFB,	Injection of H_2O_2 and addition of ammonium and phosphate salts	TCE	System operational for 9 months
Savannah River Site, SC	Horizontal air injection and extraction wells	TCE	Testing began in July 1990
Cabot Carbon/Koppers, FL	Nutrient addition in groundwater and soils above and below	PCP, bis(2-ethyl hexyl) phtahalate, DNT, dimethylphenol, PAH	Design will be completed in September 1994

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