United States Environmental Protection Agency
Office of Research and Development
CERI-90-114
December 1990

EPA

The Federal Technology Transfer Act

Opportunities for Cooperative Biosystems Research and Development with the U.S. EPA

oth the U.S. Environmental Protection Agency (EPA) and private industry seek new, cost-effective technologies to prevent and control pollution. In the past, however, legal and institutional barriers have prevented government and industry from collaborating in developing and marketing these technologies. Also, the efforts of many companies to develop new technologies have been held back by a lack of resources, such as scientific experts in particular fields or highly specialized equipment. The Federal Technology Transfer Act of 1986 (FTTA) removes some of these barriers to the development of commercial pollution control technologies.

The FTTA makes possible cooperative research and development agreements (CRDAs) between federal laboratories, industry, and academic institutions. CRDAs set forth the terms of government/industry collaboration to develop and commercialize new technologies. These agreements will, according to the Act, foster the technological and industrial innovation that is "central to the economic, environmental, and social well-being of citizens of the United States."

What can industry gain from signing a CRDA with EPA?

- **Access to high-quality science.** EPA's 12 research laboratories employ over 850 scientists and engineers and operate on a budget of approximately $450 million per year. Many of these laboratories combine world-class expertise with state-of-the-art equipment and fully permitted testing facilities. Certain types of environmental research, such as pollution prevention and control, require the collaboration of experts in many different fields. This type of interaction is readily accomplished at EPA laboratories, which employ a range of pollution control experts.
- **Expanded communication channels between government and the private sector.** CRDAs build working relationships between the government and the private sector. The different perspectives that government scientists bring to an applied R&D project can provide a knowledge base that can significantly reduce the time spent on problem-solving tasks during technology development.
- **Exclusive agreements for developing new technologies.** Under some CRDAs, companies are given *exclusive* rights to market and commercialize new technologies that result from the collaboration. Until recently, industry had little incentive to cooperate with federal laboratories because any technologies developed during joint research remained in the public domain for all to use. Now,

exclusive rights can be negotiated for some projects, though other arrangements of rights are also possible, depending on the type of CRDA.

The advantages of collaboration have prompted EPA and industry to set up CRDAs in areas ranging from reducing air pollution to cleaning up oil spills. Bioremediation, a technology that uses bacteria to break down hazardous chemicals such as spilled oil or Superfund hazardous wastes, has proved to be a particularly fertile area for collaboration (see page 6). For years, other methods of cleaning up wastes have dominated the market, but recently bioremediation has seen increasing use. CRDAs have resulted in the field application of this technology, providing an ever-expanding data base of chemicals known to be biodegraded. This technology is, therefore, an excellent example of the benefits of government and industry working together to develop new means of pollution prevention and control.

Biosystems use microorganisms, such as bacteria or fungi, to transform harmful chemicals into less toxic or nontoxic compounds. To the microorganisms, the pollutants are an energy source; they break down the pollutants in the course of getting the energy they need to live and multiply. Different organisms metabolize different chemicals, so, by using an organism in the biosystem that breaks down a particular pollutant, scientists can tailor the technology to the pollutants at specific sites. Wherever possible, development teams use native microorganisms in biosystems that they know are already metabolizing the pollutants on the site. In these cases, the number of microorganisms — and thus the speed at which a pollutant is broken down — can be increased by adding nutrients to the site. In other cases, non-native organisms known to metabolize the pollutants are introduced.

Biotransformation is an attractive option because:

- It is "natural," and the residues from the process (such as carbon dioxide and water) are usually harmless.
- It is less expensive and less disruptive than other options frequently used to remediate hazardous wastes, such as excavation and incineration.
- It holds a clear advantage over many technologies relying on physical or chemical processes: instead of merely transferring

contaminants from one medium to another, biosystems can destroy the target chemicals.

Potential markets for commercialized biosystems treatment of hazardous wastes are huge. Across the United States, thousands of state, federal, and private hazardous waste sites are currently slated for cleanup under Superfund and the Resource Conservation and Recovery Act. In addition, approximately 15 percent of the nation's four to five million underground storage tanks containing petroleum, heating oil, and other materials are leaking. Many more underground tanks will begin to leak in the next 5 to 10 years. Yet another market results from the 10,000-15,000 oil spills that occur each year, requiring cleanup of contaminated soils and waters.

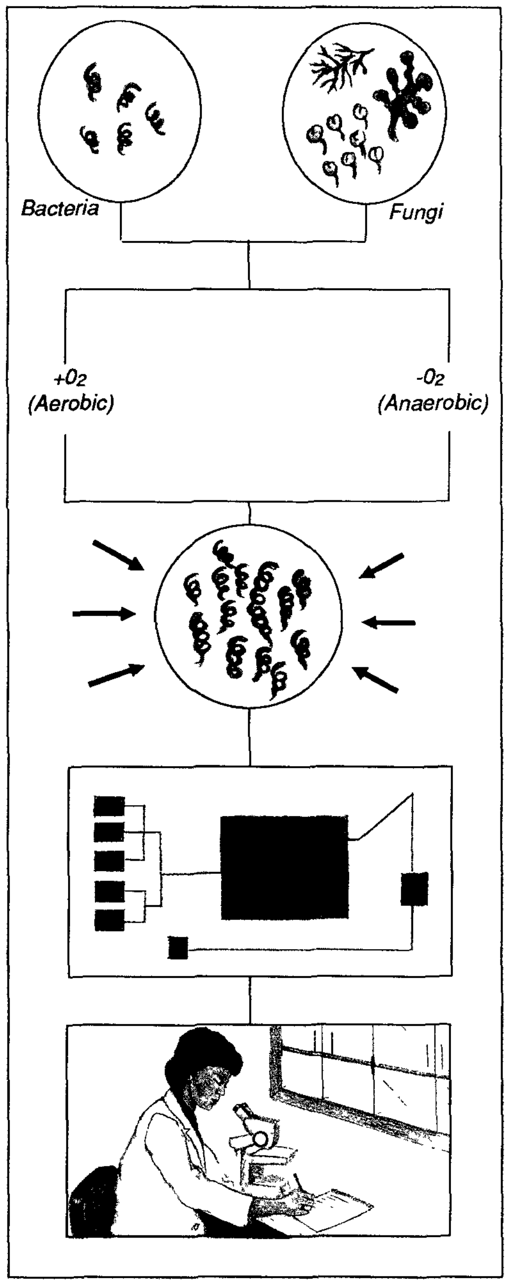
Our increasing knowledge of the biology of microorganisms that degrade wastes and of the engineering technologies needed to apply and control degradation processes has opened the doors for new biosystems technologies. Microbial treatment has already been successfully used both in the United States and in other countries for *in situ* treatment of soils contaminated with organic compounds at hazardous waste sites. Biological systems have also been used to treat soils and aquifers contaminated by hydrocarbons, phenols, cyanides, and chlorinated solvents such as trichloroethylene. Another approach to bioremediation is to isolate the enzymes that catalyze the metabolism of pollutants in the microorganisms. Once separated from the organism, some of these cell-free enzymes have been modified to break down pollutants, such as organophosphate pesticides.

These achievements have only begun to tap the potential of biosystems technologies, but they point to the rich opportunities for the emerging biosystems industry in waste management. To help develop these opportunities, EPA has initiated a major research program in this area: The Biosystems Technology Development Program.

This program is answering key research questions in the development of biosystems for treating hazardous wastes (see Figure 1). For example, can microorganisms be used to treat chemicals commonly found at waste sites — such as chlorinated solvents, polychlorinated biphenyls (PCBs), chlorinated phenols, petroleum hydrocarbons, creosote constituents, and dioxins? Can bacteria act to remove chlorine substituents (dechlorination) from synthetic chemicals? What are the limitations of biological treatment? How effectively do organisms metabolize chemicals under anaerobic as opposed to aerobic conditions? What types of organisms work the fastest? EPA invites industry collaboration to answer these questions and solve a

1. Develop the Biosystem

- Identify appropriate organisms
- Study metabolic process
- Enhance activity of organism
- Engineer the biosystem
- Demonstrate the system

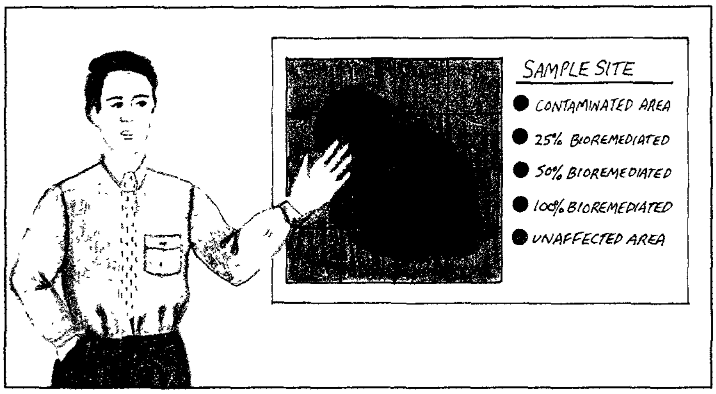


Steps in developing a biosystem.

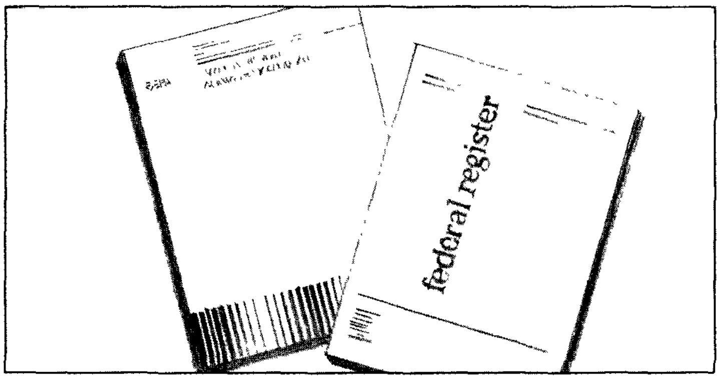
2. Implement the System

- Characterize the site
- Pollutants found on site
- Depth of water table
- Size of site
- Annual rainfall

3. Technology Transfer



4. Write Protocol and Guidelines



Alaska Oil Spill Bioremediation Project

In the wake of the *Exxon Valdez* tanker accident in March of 1989, EPA signed a cooperative agreement with Exxon to initiate a bioremediation study in Prince William Sound, Alaska. This innovative study has highlighted the great promise bioremediation holds for more timely and effective cleanup of future oil spills worldwide. Even though enhancing the natural biodegradation of oil has been extensively studied for the past 20 years, it had never before been tested on such a large scale in a marine environment.

The first challenge of the project was the need for quick response. The spilled oil, which spread over an estimated 900 miles of poorly accessible shoreline in Prince William Sound,

Bay in Prince William Sound after the Exxon Valdez *spill.*

spelled grave danger to the area's large populations of seals, sea otters, fish, and birds. A field bioremediation test had to be set up as quickly as possible so that, if the results were favorable, large-scale application could begin before the short northern summer ended. EPA met that challenge: in less than 2 months from the time of the spill, EPA developed a research plan for using bioremediation to degrade the residual oil washed up on the beaches and set up a command center in Valdez. Field tests began on June 8, 6 days after the formal signing of the CRDA between Exxon and EPA.

On designated beach sites, a team of EPA scientists applied fertilizer containing nitrogen- and phosphorus-rich nutrients to stimulate the native organisms on the beach to degrade the spilled oil. The nutrients were applied in the form of three different types of fertilizer. "Reference" test plots, where no fertilizer was added, were also set up for comparison. The striking visual contrast between the reference and fertilizer-treated plots focused immediate national attention on biosystems as treatment options for spilled oil. By July 25, large-scale application of the fertilizers began. Eventually, the fertilizer was applied to over 70 miles of Alaskan coastline.

This success is striking proof of the potential benefit of FTTA agreements. EPA demonstrated its credibility as a scientific resource to industry by providing experts in molecular biology, genetics, ecology, biochemistry, bioprocess engineer-

Aerial photograph of a bioremedial test plot that resembles a clean rectangle etched upon the surface of the beach. The cobblestone plot, which was located at Snug Harbor, was treated with oleophilic fertilizer during the summer of 1989.

ing, risk assessment, microbial ecology, ecological toxicology, and mathematical modeling. Exxon had few microbiologists on staff and little experience in field testing of pollution control technologies. EPA handled the nutrient addition, monitoring, and analyses necessary for carrying out this project.

Under the CRDA, Exxon paid for all the costs of field operations directly applicable to the bioremediation study. To ensure the independence of study results, EPA paid and was responsible for oversight and management of the project as well as conducting the field work.

variety of common, real-world pollution problems, such as the 1989 oil spill in Alaska.

Through the Biosystems Technology Development Program, EPA has established a strong research base in six key areas of biosystems research — liquid reactors, soil/sediment treatment, combined/sequential treatment, ground-water treatment, metabolic processes research, and risk assessment.

Liquid reactors. In liquid reactors, toxic and hazardous pollutants in liquid form are brought into contact with microorganisms to enhance degradation. Landfill leachates are a good example of a type of liquid waste that could be treated with this type of biosystem. Nearly 130 million tons of solid waste is disposed of each year in landfills across the nation, and various inorganic and organic chemicals often leach from the waste into drainage water. One area of EPA research focuses on using liquid reactors at publicly owned treatment works (POTWs) to treat this leachate stream.

As POTWs are now operated, many do not handle liquid wastes well enough: pollutants may still pass through the system unchanged and be released into salt or fresh water; aeration results in air stripping of volatile toxicants into the air; and many of the toxicants associated with the residual sludges are not completely dechlorinated and destroyed. Through improved engineering and operational controls, existing facilities may be modified to handle these wastes. In one current project in this area, EPA researchers are examining how to treat leachate in a biofilter, where the pollutants are broken down by microorganisms. Another set of experiments is showing that a combination of anaerobic and aerobic methods in a bench-scale treatment system can result in 30 to 70 percent removal.

Soil/sediment treatment. The soils at many industrial sites are contaminated with complex mixtures of pollutants. Cleaning up these soils *in situ* with biosystems is potentially much more effective and inexpensive than excavating the soils. Three classes of industrial chemicals are currently the focus of EPA biosystems research on soils and sediments: pentachlorophenol (PCP), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs).

The first of these, PCP, is a common soil contaminant at wood-preserving facilities. EPA researchers have shown that a white-rot fungus, *Phanerochaete chrysosporium*, can reduce the level of PCP in the soil at these sites. A field study was set up at a former tank farm where for 12 years aboveground storage tanks were filled with wood preservatives and diesel fuel, which then leaked into the surrounding soil. Two different strains of the fungus both noticeably depleted the levels of PCP at the field site. Another EPA project showed that when anaerobic conditions were induced and maintained, PCP and other chlorinated compounds were degraded in freshwater sediments from areas as diverse as Georgia ponds, the East River in New York City, and Lake Borek in the Soviet Union.

High-molecular-weight PAHs, some of which are carcinogens, are associated with wood-preserving plants, coal gasification sites, and petroleum refineries. The estimated 700 wood-preserving plants in this country, for example, use more than 4,960 tons of creosote per year, some of which leaks from holding tanks and treatment areas into the soil. Creosote is a complex mixture of over 200 individual compounds. Research on *Pseudomonas paucimobilis* under a CRDA shows that this bacteria can metabolize these chemicals (see page 10).

Another class of toxic compounds, PCBs, was used heavily for about 50 years in a number of industrial applications. In the 1960s and 1970s, researchers discovered that PCBs, which resist biological degradation, were accumulating in the fatty tissues of animals and fish. Even though their use has been largely discontinued, an estimated half million tons of PCBs remain in landfills. One EPA project is assessing the rate at which two different bacterial strains metabolize PCBs and pinpointing the enzymes that are responsible for initiating the degradation.

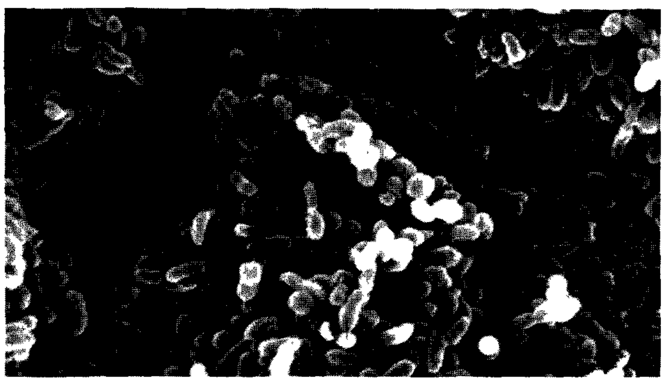
Combined and sequential treatment. Most hazardous waste sites contain complex mixtures of persistent organic and inorganic contaminants that can be cleaned up only by a combination of treatment techniques. EPA researchers are developing methods to combine various physical, chemical, and biological treatment technologies, and comparing the effectiveness of the various combinations. For example, a chemical treatment — adding potassium polyethylene glycol (KPEG) to the soil at a site — may be used to dechlorinate PCBs. Then, biological treatment, which is more effective after dechlorination, can be used to complete the soil restoration. In one project, researchers are combining KPEG treatment with composting to enhance biodegradation in contaminated soils. These initial studies will indicate how effectively composting enhances the metabolic activity of the organisms at the site.

Ground Water. Effective bioremediation of ground water is limited by the geology, hydrology, and geochemistry of the subsurface environment. In this area, EPA researchers are examining how to supply electron acceptors, such as oxygen or hydrogen peroxide,

Example of EPA Cooperative Agreement with Small Business: Southern Bio Products

In 1989, Southern Bio Products (SBP) signed a cooperative research and development agreement (CRDA) with EPA's Gulf Breeze Environmental Research Laboratory in Gulf Breeze, Florida. Under this agreement, SBP provides funding and expertise as part of an effort to investigate the use of microorganisms to metabolize, or degrade, polycyclic aromatic hydrocarbons (PAHs). High-molecular-weight PAHs are carcinogens and thus represent a risk to human health and the environment.

Creosote waste sites, coal gasification sites, and petroleum refinery sites all can contain PAH-contaminated soils. In an

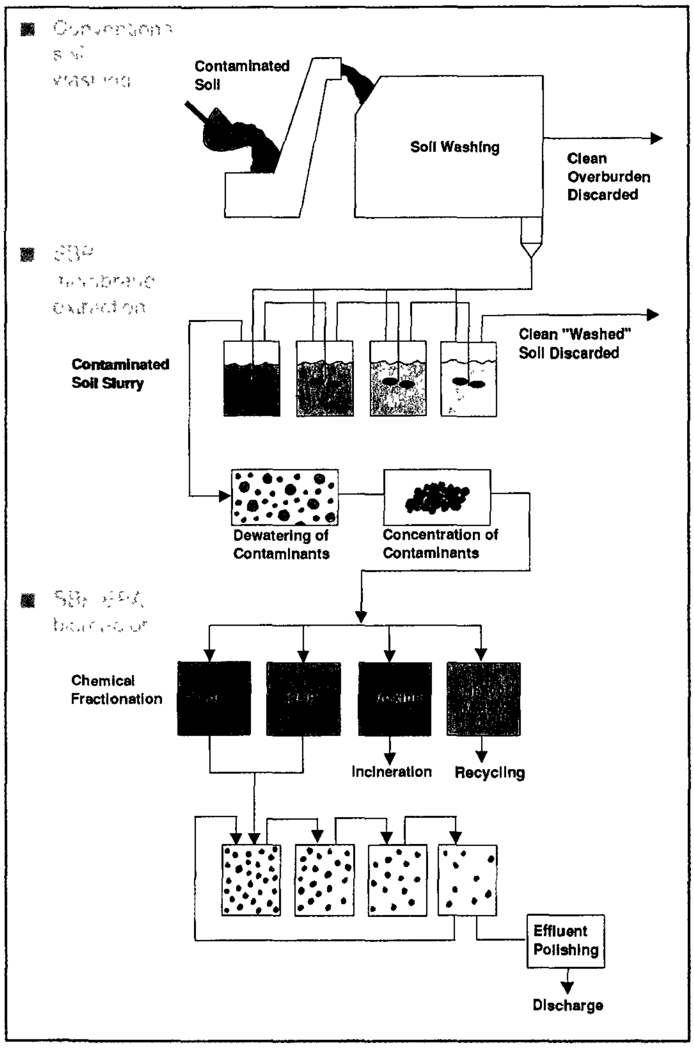


Electron micrograph of Pseudomonas paucimobilis. *(Magnification x 10,000.)*

effort to make bioremediation a viable alternative for such sites, the project team isolated a strain of bacteria that uses PAHs (e.g., fluoranthene) as a sole source of carbon and energy for growth. The team then examined the possible pathways by which the bacteria break down the PAHs.

Next, the team developed a three-phase sequential system to treat creosote- and similarly contaminated soil and water. The steps in this process entail soil washing, a membrane extraction process that reduces the waste to be treated by 100- to 100,000-fold, and biodegradation of extracted pollutants. In the past year, EPA submitted three patents for steps in this new technology, which will be field tested within one year. Under this CRDA, EPA will grant an exclusive license to SBP to commercialize the patented technology.

For Southern Bio Products, a relatively new company, the CRDA provided a way to develop a product quickly. According to a representative of the company, the cooperative efforts of the Gulf Breeze laboratory under the FTTA agreement stimulated information flow and cross-fertilization of ideas between EPA and SBP. SBP worked primarily with the microbial



Schematic diagram of SBP/EPA tri-phasic treatment process: soil washing, membrane extraction/concentration, and biodegradation.

ecology and biotechnology branches at Gulf Breeze, but also had access to the ecotoxicology and pathobiology branches.

to promote aerobic processes in contaminated ground water. They are also working on ways to develop or improve anaerobic biological processes for degrading contaminants in the subsurface.

In one ground-water study, researchers are assessing whether they can stimulate indigenous microorganisms in the subsurface to remove carbon tetrachloride from contaminated aquifers. Pilot-scale field evaluations suggest this form of bioremediation will work. Another project deals with creosote that has infiltrated into the soil around wood-preserving plants and moved into the water table. Researchers have shown that some of the organic compounds in creosote can be anaerobically degraded as they move down through the aquifer.

Metabolic processes research. EPA's metabolic processes research generates a better understanding of the processes by which microorganisms degrade chemicals, expanding the types of organisms that can be used in biosystems technologies. Based on the insights gained from this research, scientists can then choose indigenous organisms or genetically engineered organisms to meet needs in pollution cleanup and control. In one research project, EPA is currently developing systems to biodegrade pollutants formed as combustion products of synthetic fuel generated from fossil fuels. These heterocyclic compounds are known to be persistent in the environment, but researchers are examining the metabolic processes by which bacteria can break them down. Another study is focusing on a single pollutant: trichloroethylene (TCE). Examination of bacteria already shown to degrade TCE led to a better understanding of the metabolic process by which TCE was oxidized. As a result, EPA scientists have identified seven more strains that can degrade this pollutant.

Risk assessment. Biodegradation can result in incomplete mineralization with the formation of intermediate breakdown products. Before environmental engineers can adopt a biologically based remediation technology, researchers must assess the potential ecological and human health effects associated with each waste management option. In the area of human health, EPA has established a research program to improve risk assessments.

These projects and others will result in many advances in bioremediation within the next few years. Enhancing the activities of microorganisms to hasten the degradation of chemicals is expected to become commonplace. Exploiting cell-free bioproducts, such as enzymes, to treat a wide range of pollutants will also become an established technique. Under the FTTA, industry can both participate in and catalyze this rapid growth of biosystems technologies. By seeking a *synergistic relationship* with EPA scientists, industry can achieve what one researcher called a "perfect union" of expertise, opportunity, and market savvy.

The procedure for setting up a cooperative R&D or licensing agreement under the FTTA is designed to encourage collaboration between industry and EPA laboratories. For industry, the key advantage of the process is the speed and ease with which the agreements can be negotiated and signed. CRDAs are not subject to federal contracting or grant regulations. In addition, each laboratory director has the authority to establish CRDAs for that particular lab, and this decentralization of the decision-making process reduces the administrative procedures involved.

Another important advantage is that CRDAs are flexible enough to fit the goals of many different sizes and types of companies. For example, under the FTTA a company can support applied research at an EPA laboratory while reserving first rights to involvement in any technology that results. Or, if the scientific mechanism by which a company's product works is unclear, the company can cooperate with an EPA laboratory to identify this mechanism. A company can also share space and equipment with EPA (as well as with a third party, such as a university or another company) in a combined effort to develop a new technology. If a CRDA results in a patentable technology, that invention can be patented by either the federal laboratory and/or the company (depending on the agreement).

Under these CRDAs, EPA may provide technical expertise, facilities, equipment, staff, or services. EPA may not provide direct funding to the outside cooperator, although the cooperator may provide funds to EPA.

The FTTA, therefore, provides a potent mechanism for EPA laboratories to work with the private sector in developing new pollution control technologies and bringing them to the marketplace. The achievements of CRDAs in bioremediation have aided EPA in its mission to remove or minimize the effects of pollutants in the environment, while at the same time catalyzing the development of the emerging biosystems industry. The CRDAs already in place suggest that cooperative agreements between industry and government will prove highly successful. How could a CRDA help your company develop a pollution prevention or control technology? Write to the individuals listed on the next page for further information.

- Environmental Research Laboratory, Athens, GA (ERL-Athens)
  EPA Contact: Dr. John Rogers, U.S. EPA, College Station Rd., Athens, GA 30613 (404) 546-3128
- Environmental Research Laboratory, Gulf Breeze, FL (GBERL)
  EPA Contact: Dr. Hap Pritchard, U.S. EPA, Sabine Island, Gulf Breeze, FL 32561 (904) 934–9260
- Risk Reduction Engineering Laboratory (RREL)
  EPA Contact: Dr. Al Venosa and Dr. John Glaser, U.S. EPA, 26 W. Martin Luther King Dr., Cincinnati, OH 45268 (513) 569-7668 and (513) 569-7568
- Robert S. Kerr Environmental Research Laboratory, Ada, OK (RSKERL)
  EPA Contact: Mr. Dick Scalf, U.S. EPA, P.O. Box 1198, Ada, OK 74820 (405) 332–8800
- Health Effects Research Laboratory (HERL)
  EPA Contact: Dr. Larry Claxton, U.S. EPA, Research Triangle Park, NC 27711 (919) 541-2329
- Center for Environmental Research Information (CERI)
  EPA Contact: Dr. Fran Kremer, U.S. EPA, 26 W. Martin Luther King Dr., Cincinnati, OH 45268 (513) 569-7346

For information on the Federal Technology Transfer Act (FTTA), licensing agreements, or CRDAs, contact:

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