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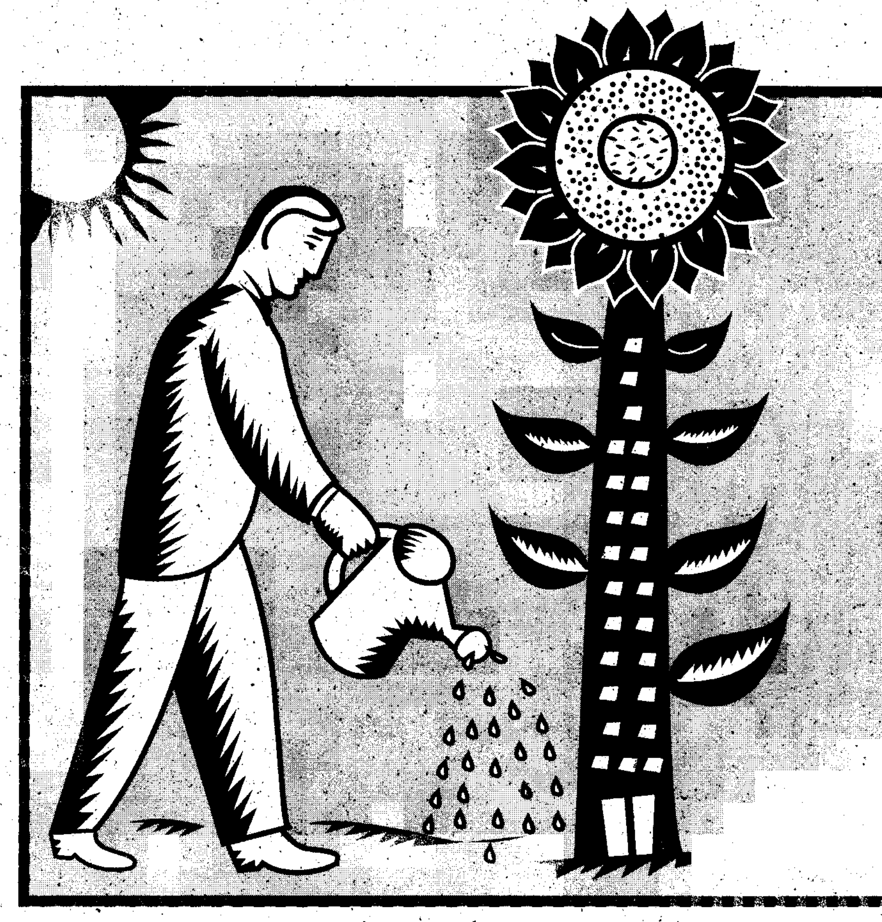
CLEANUP TECHNOLOGIES



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marketing brownfield CLEANUP TECHNOLOGIES

Interest in brownfield redevelopment has surged over the past decade, due in part to a combination of federal, state, and local programs aimed at reducing regulatory burdens and mitigating liability. Cleanup and redevelopment, however, have focused on brownfields with contaminants that are more amenable to standard cleanup technologies (dig and haul for contaminated soil, and pump and treat for polluted groundwater), and/or high real estate values. Yet since these traditional cleanup approaches often can be inadequate or expensive, new technologies—which can mitigate the less tractable contaminants, lower costs, or reduce treatment time—are needed to spur interest in redeveloping many of the remaining brownfields.

Numerous obstacles exist to the use of innovative technologies. New approaches, by definition, are unproven, are less familiar to regulatory or permitting authorities, and may take longer to receive the approvals and permits needed to begin cleanup. The effectiveness of cleanup technologies, moreover, tends to be quite site-specific, and new approaches often have not been tested or benchmarked in diverse enough conditions to give assurance of their success. Some innovative technologies, while effective, also may be more time-consuming than standard methods. Finally, the liability problems associated with Superfund have made the banking and financing community cautious of new approaches. Liability concerns have been dampened considerably by federal and state actions, but financiers, in short, are still conservative, and they avoid new technologies that have not been endorsed by professionals and/or practitioners.

Several federal programs and some state initiatives test and demonstrate innovative brownfield technologies, as well as acquaint state officials, vendors, and environmental consultants with their cost and performance. Most of these programs are less than five years old, and many are more recent. Conclusions about their effectiveness would be premature, but the rapid progress within the private sector of a few new technologies—notably, soil vapor extraction—and burgeoning interest in others—like phytoremediation—probably owe something to these testing, demonstration, and outreach programs.

Despite such clear progress, controversy exists over the appropriateness of Washington taking any role in advancing technologies that confer private gain, other than to advance the basic science that underlies much technology development. Some believe government support for developing commercial or even precommercial technologies smacks of corporate welfare, and others argue that federal technology programs amount to "picking winners" and bias the market in inefficient ways.

However, the rationale for government's involvement in cleanup technologies is strongly reinforced by two factors. First, government itself uses these technologies. The Departments of Energy and Defense, in particular, own many contaminated sites that cannot be used and may pose public health hazards if not cleaned. As a significant consumer of cleanup technologies, government properly should bear some of the cost of developing them, and it would be inefficient not to devote some effort to disseminating information about the results of its own technology development, demonstration, and testing programs. Second, the market is not as effective in signaling the need for and rewarding innovative activity in environmental technologies as it is in more purely commercial enterprises. These factors should prompt increased government work on site assessment and cleanup technologies, leading to their enhanced use in the private sector.

INTRODUCTION

Interest in brownfield redevelopment has grown quickly over the past decade, particularly in the more densely populated regions of the country—the Northeast and Midwest. Yet advances are tempered by contamination that may be extensive and costly to mitigate. Traditional approaches to cleanup—pumping and treatment of contaminated groundwater, and incineration or solidification/stabilization of contaminated soils—can be quite expensive and time-consuming, can create their own environmental problems, and may still not be suitably effective.[1] New technologies offer the promise of greater effectiveness and/or lower cost, but as with any new technology, they also may present greater risks. (See the appendix for a brief description of site cleanup technologies.) New technologies are, by definition, unproven under field conditions, and new users risk taking time and spending money on a solution that doesn't work.

Nevertheless, given the substantial limitations and high costs of conventional treatment technologies, the pressure to find cheaper and more effective technologies for assessment and cleanup of brownfields will continue to build. Governments at several levels have tried many ways to reduce the barriers to such innovations, and there is much we can learn from these efforts.

BARRIERS TO NEW ENVIRONMENTAL TECHNOLOGIES

In the United States, we generally accept that markets are effective signal processors: that demands for goods and services will be transmitted to people who can meet those demands, and that the market eventually will settle on an optimal price. But the market for many environmental technologies is attenuated at best.

Unlike many of the products traded in markets, environmental goods and services traditionally have not been owned or priced. Putting economic value on common-property resources like groundwater has been handled primarily through regulation (e.g., standard setting, prohibitions, technology specification), with some notable exceptions.[2] Regulation tends to create markets that look different from commercial markets in fundamental ways.

Whereas markets created by regulatory targets often are circumscribed by their targets, open-ended markets have no limit to their ability to absorb new technology so long as there is some advantage to it. For instance, ever since computers were introduced to commerce, the pressure for greater computational power and speed has been intense. Generations of computer engineers and systems designers have produced machines that seemed overdesigned even for the most extravagant applications, only to find their designs running into limits of capacity and speed within a few years of introduction. Predictions like Ken Olsen's, that there was no reason why anyone would want a computer in the home, or Bill Gates' reputed assertion that nobody could use more than 640K of random access memory, seem quaint when viewed with only a few years' hindsight.

Markets for environmental goods and services, in contrast, tend to be limited by numerical standards, with little incentive to exceed the specified performance. Technologies that can exceed the minimum standard often languish. In a few cases, the constraints are even tighter; while few environmental statutes specify the use of a particular technology, many use design standards based on best available technology or best practices. The Clean Water Act, the Resource Conservation and Recovery Act, and the Clean Air Act all make extensive use of design standards. While design standards may encourage innovation, constant vigilance and investment are needed to provide continuing incentives. In fact, many observers regard design standards as de facto technology specifications, especially where the costs are high of proving that alternative technological approaches meet or exceed the standard.[3]

New technologies face an uphill battle for survival in any area, regardless of the degree of market development or strength of demand. Yet these battles seem particularly pronounced in environmental applications. Obstacles facing innovative technologies include technical problems, financial barriers, liability concerns, and permitting uncertainties.

TECHNICAL BARRIERS

There is always a risk that a new technology simply won't work, or that the solution of critical problems is more painful than anticipated. Examples abound of research initiatives aimed at apparently reachable goals that failed, sometimes after extraordinary expenditure. For instance, advances in many kinds of battery technology have been more difficult and time-consuming than predicted; energy from nuclear fusion has been both expensive and elusive.

In cases where technology development has not kept pace with expectations, people tend to become skeptical that solutions exist at all. Hence, when a new technique does appear, it must hurdle this cynicism, as well as the inevitable bugs that accompany the introduction of new technology into practice.

In the cleanup of contaminated soil and groundwater, our understanding of the factors that contribute to a technology's success is limited. We know that subsurface geology, chemistry, and hydrology have a great deal to do with the effectiveness of any cleanup technology, but we lack the specific knowledge of the interplay of these factors in order to predict accurately the time, cost, or effectiveness of many mitigation technologies.[4] Some problems have been especially troublesome, including the cleanup of certain types of contaminants (e.g., non-aqueous phase liquids, or NAPLs) or any type of contamination in a complex geologic matrix.

Developing and testing any new technology involves a period of uncertainty and experimentation, and that period is often lengthy. Technologies must be tested under field conditions, by real users, before they are well understood and reliable. For example, ENIAC, one of the first electronic computers, consumed hundreds of kilowatts of electricity and required armies of technicians to keep running, yet its mean time between failures (MTBF) averaged only 10-15 minutes.[5]

In their early stages, new technologies are frequently more expensive than conventional alternatives, although successful technologies typically move down the cost curve very rapidly. It is almost invariably true that new technologies are rough around the edges when first introduced. This is more of a handicap to some technologies than to others. In some areas—advanced computation is a good example—users often will put up with great inconvenience and quirkiness in exchange for the technology's increased power. The technology becomes attractive of itself, not merely as a means to an end.

In environmental applications in general, and soil/groundwater cleanups in particular, however, there is no special attraction in the technologies themselves. Cleanup is simply a means to a different end, often a real-estate development or transaction. Failure of a new technology to perform as advertised is at best a significant inconvenience, and may at worst scrub the whole project. On the other hand, the fact that conventional technologies for groundwater treatment are frequently ineffective in achieving regulatory goals[6] will continue to drive interest in new technology.

FINANCIAL BARRIERS

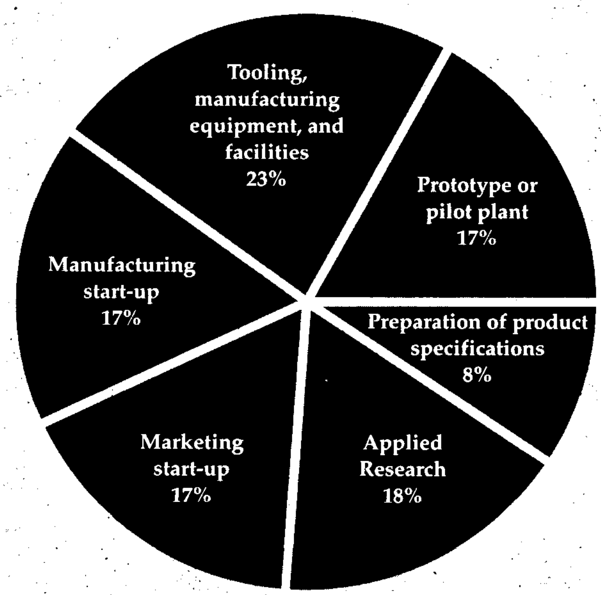
In the past few years, financial obstacles to brownfield redevelopment and cleanup have been reduced significantly. This progress, in turn, increases demand for new and better approaches to cleanup. However, financial barriers still present significant obstacles to both technology development and technology adoption in any field.

For technology developers—who range from individual inventors with bright ideas to major corporations—the costs of bringing a technology from "aha!" to market are often described as a "Valley of Death."[7] For individual inventors or small businesses, advancing a new technology from concept to proof-of-concept to prototype may easily consume hundreds of thousands to millions of dollars and a decade or more. Businesses whose product line consists of new technology often go many years before turning any profit. The National Research Council reports that startup businesses in site remediation have done poorly on Wall Street;

between the Initial Public Offering (IPO, or first offering of stock to the public) and 1996, six of eleven remediation startups' stock values dropped, often significantly.[8]

New technologies offer advantages in cost, time, or effectiveness. Yet in the early stages of adoption, many cost-saving technologies are anything but. New technologies typically enter the market at prices much higher than their alternatives, or at prices that only a few users can afford. The earliest users of new technology—referred to as bleeding-edge users—often make their own modifications and patches, many of which are incorporated into successive generations of the technology. For these users, and other early adopters, lower cost rarely is seen as an advantage of a new technology; early adoption is more likely to be based on other factors. For other users, however, even much-improved effectiveness may be neutralized by high initial costs or bugs.

FIGURE 1.
Percent Costs of Innovation, by Activity



Source: Edwin Mansfield, "Industrial Innovation in Japan and the United States," *Science*, September 30, 1988, p. 1770.

Financial risks pose a significant barrier to the use of innovative technologies in brownfield assessment and cleanup. That risk stems partly from the technical uncertainties, and partly from time and liability.

Development and launch of new technologies are part of a resource-intensive process, with half or more of the expense occurring after a technology has been demonstrated to work (Figure 1). Most inventors fail to anticipate this schedule; experienced inventor consultants often preach that "the technology is 5 percent of commercialization." Many inventors and small-business innovators focus exclusively on developing the technology itself, and often are unprepared for the time and expense needed to create a functional business. An enterprise or inventor with a portfolio of only one product faces especially high odds.

Moreover, the expense and performance of new technologies are not well established, which can compound the wariness of financiers. The problems this uncertainty creates are much more daunting for small than large businesses, since small firms are more likely to have insufficient earnings from other lines of business to carry them through difficulties. Many small companies are formed around one or two products, or a single technology. In addition, banks tend to view small companies as higher risks, and charge them higher interest rates.[9] As a result of these factors, small companies marketing new remediation technologies have not performed well, and firms in the remediation technology industry are consolidating and diversifying.[10]

LIABILITY CONCERNS

The amount of time that assessment and cleanup take can be the difference between success and failure in brownfield development. Unless an entity other than the potential developer (e.g. the municipal government or a previous landowner) has assessed and/or cleaned up a piece of property, those activities can expand the timeframe of a real-estate deal in which interest costs on a construction loan are a key expense. This time pressure can discourage use of innovative remediation technologies,[11] but may increase interest in innovative site assessment technologies (see Box 1: An Innovative Assessment Tool).[12] The simple reason for this dichotomy is that some innovative assessment technologies, such as the geoprobe,[13] provide information rapidly and often more inexpensively than do traditional methods. However, the traditional method of cleanup, at least on sites with no groundwater contamination and no deep soil contamination, is dig-and-haul, and it usually can be accomplished more rapidly than many of the innovative, in situ technologies like bioremediation or phytoremediation.

CERCLA (Comprehensive Environmental Response, Compensation and Liability Act, or Superfund) establishes the liability regime that affects brownfield sites as well as Superfund sites.[14] CERCLA liability is strict, joint, several, and retroactive, meaning that current or past owners, even if they are not responsible for the contamination, may be held responsible for cleanup. So may those who arrange for treatment or disposal of hazardous substances, or those who transport hazardous substances.[15] Superfund cleanups may run to tens of millions of dollars or more.[16] While brownfield cleanups typically cost much less, the extent of contamination is unknown at many sites. Because banks also may be held liable for cleanup costs when they acquire properties through default, they often are unwilling to provide loans for cleanups or acquisition of contaminated sites. Although lenders are not liable as a result of mere ownership resulting from foreclosure, banks may be held liable if they had a role in managing a contaminated site. These factors—the potential liability for cleanups that prove to be difficult and complex, together with strict liability standards—exert a chilling effect on the use of new, unproven technologies.

A number of initiatives—including the use of comfort or no-action letters, state memoranda of agreement, covenants-not-to-sue, and information and outreach programs conducted by EPA and officials at other levels of government—have given many developers, landowners, lenders, and investors concrete tools for managing liability. Without new federal legislation, however, liability will always be an issue, particularly if there are significant opportunities to revisit a cleanup that has received state approval, which many letters or covenants still provide. Liability also will remain an issue where there is residual contamination.[17] A state's brownfield or voluntary cleanup program can provide relief only from action under state law, and the possibility of federal action cannot be eliminated.

Efforts to reduce liability concerns have paid off modestly. In some areas, both developers and lenders are becoming better acquainted with the real risks posed by brownfield redevelopment, including the fact that there have been no significant environmental damage claims brought against redevelopers by third parties.[18] EPA has been willing to sign state memoranda of agreement (SMOAs) stating that the federal agency does not anticipate taking action at sites involved in state-approved programs in the absence of a serious threat to health or the environment.[19] As of 1996, EPA had signed SMOAs with eleven states, and since 1991 it has distributed about $25 million to help states develop voluntary cleanup programs that are the basis of the SMOAs. EPA's

BOX 1

An Innovative Assessment Tool

Technologies that speed up assessment and cleanup can be enormously helpful to brownfield redevelopment, even if they offer no other advantages. Rapid assessment technologies are being developed that greatly simplify decision making. For example, the application of a new site application tool, Niton, at a metals-contaminated site in Worcester, Massachusetts, helped to refine both the technology and save money and time in treatment. The Niton tool provided real-time feedback on the degree of contamination—with a turnaround time of 15 minutes rather than three days, as is conventional. The tool itself originally was developed to sample paint for lead contamination, and is being adapted by the manufacturer for use in soil sampling on contaminated sites. The quick turnaround allowed immediate excavation of the contaminated soil on the site. However, there were a few bugs. Dave Dunham, executive director of the Central Massachusetts Economic Development Authority, reported that the manufacturer's recommended methods for sample preparation resulted in higher contamination readings than were actually present. As a result of this trial, Dunham reports, the manufacturer is altering its recommendations for sample preparation. Even with this bug, however, Dunham was enthusiastic about the new technology, for it allowed immediate decisions in the field and avoided expensive equipment sitting idle on the site, waiting for lab results.[53]

Environmental Financial Advisory Board has encouraged EPA to enter into SMOAs with other states, to have these memoranda give states the lead role in addressing sites not on the Superfund National Priority List, and to delineate clearly the roles of states and EPA.[20] However, there have been some controversies. The Environmental Council of the States (ECOS) regarded EPA's guidance on developing SMOAs as intrusive, with the potential to undermine existing effective state initiatives, and that organization of state environmental officials also asked EPA to withdraw its guidance and not to link future voluntary cleanup funding to SMOAs.[21]

PERMITTING UNCERTAINTIES

Delay can be a significant barrier to the launch of a new business or technology. Brownfield redevelopers often find they need to obtain multiple permits and approvals in order to move a project forward. Before the development of state voluntary cleanup or brownfield programs, many states used CERCLA or RCRA (the Resource Conservation and Recovery Act) regulatory procedures in brownfield cleanup, and some states still treat brownfields under such enforcement-driven programs. This means, among other things, an investigation must weigh different remedial alternatives, and a redeveloper might have to obtain several different permits. According to one investigation,

> *"For example, a permit may be required for treatment of media (e.g., ground water or soil) containing hazardous wastes or for discharges resulting from cleanups to surface water bodies. Permit requirements can at best delay a cleanup and at worst prohibit a cleanup altogether….The [National Oil and Hazardous Substance Contingency Plan], permitting, and other oversight procedures may be important at large sites with complex contamination or geology, and where potential for human exposure is high. However, for many, if not most sites, rigorous regulatory procedures may needlessly delay cleanup."*[22]

When and whether permits are granted is sometimes difficult to predict, and it can take months or years to obtain all the requisite paperwork before beginning a project. The technology for cleanup itself also may require a permit or an approval. These are granted, most often, on a site-by-site basis, rather than on a technology basis. Finally, while federal Superfund sites are not required to obtain a permit for activities performed entirely on-site, there is no analogue for brownfields, which are less contaminated.[23]

> ***"No doubt a blanket approval for a certain technology can be an enormous boost, yet presumptive remedies or blanket technology approvals also can suppress interest in further innovation or alternative technologies."***

Whether site-specific approvals themselves are a hindrance to the use of innovative technologies is debatable. No doubt a blanket approval for a certain technology can be an enormous boost, yet presumptive remedies or blanket technology approvals also can suppress interest in further innovation or alternative technologies. The CERCLA regulatory process, which requires investigation of alternative remedies, would seem to foster the consideration of innovative but little-known technologies that could otherwise be overlooked. CERCLA itself, with its strict cleanup and liability standards, probably drives the development of cleanup technologies for contaminants and sites that are difficult to treat with conventional methods. On the other hand, unfamiliarity with innovative technologies on the part of people and agencies responsible for approvals is a source of delay and uncertainty. Developers wanting speedy approvals may avoid the use of innovative technologies if a conventional method, though inferior, is adequate.

Most states have provided for accelerated permitting and approvals through voluntary cleanup or brownfield programs, often because of the onerous requirements and delays associated with enforcement-driven programs. EPA's Environmental Financial Advisory Board urges that more states adopt this accelerated approach, recommending that municipalities and states expedite paperwork on zoning or variances, building permits, cleanup standards, and remedy selection for brownfield projects.[24] By itself, this action probably would do little to improve the climate for innovative technologies in brownfield remediation (though it could add incentives for use of innovative assessment technologies). However, expedited permitting and approval, combined with a program to acquaint potential users or stakeholders with innovative technologies, could provide a substantial boost.

Expedited approvals can help move brownfield cleanups, but sometimes at an environmental price. A recent study concluded that state voluntary cleanup/brownfield programs often were effective at moving many sites out of legal limbo and into development, but that cleanup was less assured. In Michigan, according to the ITRC, [the Interstate Technology Regulatory Cooperation working group of the Western Governors Association), "The cumulative result of the technical changes made by [the Michigan Department of Environmental Quality] under the 1995 amendments is that less cleanup is occurring at each site."[25] The Colorado voluntary cleanup program provides no written technical guidance, discourages risk assessments, and does not require that approved land uses on processed sites be included as a deed restriction—meaning that future compliance with approved land use is not assured. According to the ITRC report, limited funding also means "effective state review and support at only the smaller, least complex sites."[26]

GOVERNMENT'S ROLE IN INNOVATIVE TECHNOLOGIES

The U.S. government for several decades has taken some part in developing and encouraging new technologies. The justification for this activity, in a society firmly rooted in free-market economics, is partly government's role in providing public goods, and partly a belief that the market has some shortcomings.

The federal government always has been expected to advance technologies in areas that were unambiguously for public purposes. However, public purpose is an ambiguous concept, and the debate over where to draw the line between public good and private gain is, putting it mildly, spirited.

Many things that once were regarded as public goods now are viewed differently. Postal and delivery service has been increasingly privatized, with the emergence of the venture-capital-backed Federal Express and other specialized services for delivery of information. While cable, telephone, railroads, and electric utilities were heavily regulated by government on the basis of their natural-monopoly characteristics and the redundancy of creating multiple transmissions and delivery infrastructures, all have been deregulated or are in the midst of deregulation. The public's view of the public sector's proper role has narrowed.

Whether environmental amenities are public goods or private has never been firmly established. While private parties can claim some rights to the air, water, and subsurface of property, all these amenities retain some common-property attributes, and the responsibility for maintaining their quality has fallen to governments. Statutes that protect air, water, soil, and groundwater quality have defined certain limitations to the rights of private ownership, and established remedial processes.

The public sector has taken on some responsibility for advancing technologies. The rationale for government's role in promoting innovative technologies is an economic one, resting on market failure. According to this widespread view, the benefits of scientific inquiry and (to a lesser extent) technological advance are distributed widely in society. However, because scientific understanding and technological innovation almost invariably build on research done outside any individual project, scientists and innovators cannot capture the full value of their work to society. Therefore, it is in the public interest to promote scientific and technological advances in order to make up for the inability of private markets to provide incentives that match the value of innovation. This position is straightforward, but like the public-purpose argument, much more difficult in practice than in theory.

At any moment in the development of a new technology, there are usually several choices of future path, and there is rarely enough money to pursue all promising leads. Government has the capacity to be such a substantial benefactor, performer, or customer for R&D that its preferences may bias the development of a technology, sometimes in non-optimal ways for eventual civilian applications. For example, military interest in development of numerically-controlled (NC) or computer-numerically-controlled (CNC) machine tools is blamed frequently for putting the U.S. machine tool industry in a questionable competitive position. To some analysts, the machine tool industry's early focus on producing gold-plated military systems is a principal reason for the decline of the U.S. industry.[27] To others, the industry's conservative management and a lag in adoption of microprocessor-based controllers —attributable to management, not to military demands—is more plausible. Nevertheless, government's involvement in what ended up as an unfortunate episode for an American industry continues to implicate federal involvement as a risky way to advance new technologies that have commercial applications.

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It is also true that government has done a great deal to advance many technologies in ways that have proved quite beneficial for the U.S. economy as a whole, and certain sectors in particular. There is little doubt, for example, that the National Advisory Committee for Aeronautics (NACA) in the early part of the twentieth century laid a critical foundation for American competitiveness in aircraft manufacturing and services. NACA's successor, NASA, continues to advance aeronautics technologies for both military and civilian applications, for example, in testing new airframe designs in wind tunnels and through advanced numerical simulation, cockpit and human factors design, management of helicopter loads, and subsonic and supersonic laminar flow. Similarly, the advances made in both development and diffusion of agricultural technologies by the U.S. Department of Agriculture and the Agricultural Extension Service have been instrumental in making U.S. agriculture one of the most productive systems in the world. Department of Defense involvement in the development of electronic computation and microelectronics launched both the computer and semiconductor industries in the United States.

Combined with the concern over biasing technology development away from private-sector needs is the locking in of certain technologies. In certain types of markets, there is a tendency to commit to a standard or common technology, not necessarily because of technical superiority, as neoclassical economics would predict. The most often-cited example is the QWERTY keyboard. Early in the development of the typewriter, there were many competing keyboard layouts. The tendency of manual typewriter keys to jam or stick when operated very rapidly led to a preference for a keyboard that slowed the best typists down—and that, in turn, meant a keyboard that obliged typists to use their least dexterous fingers (the ring and pinky fingers) relatively heavily. The greater operability of typewriters with the QWERTY keyboard created a preference, which in turn meant that more typists studied and learned to operate that keyboard layout, and thus preferred machines with keyboards they had mastered. The rest is cliché. Today, most typists in the United States probably use computer keyboards or electronic typewriters where key jamming is not even possible, yet the nearly universal prevalence of an outdated keyboard design persists.

The fact that the QWERTY keyboard proved durable long after the source of its advantage disappeared is enough to make us cautious about interventions that could create similar technology lock-in. Technology lock-in can happen in the purely private market, with no government involvement—the QWERTY example is a case in point—but the public policy issue is sharper if government's intervention helps to lock in sub-optimal technologies.

While most of the concern about locking in commercially suboptimal technologies has to do with defense support, technology lock-in can create the potential for one firm to dominate an industry.[28] While the market alone can create monopoly power and technological bias or lock-in, the idea that government intervention may have these effects troubles many U.S. policymakers. While these possibilities probably do not outweigh the advantages of government support for most decision makers, they do have implications for the design of government technology programs. To be considered effective, such initiatives must provide sufficient incentives to encourage technologies that would not be developed without public participation, but they must avoid creating biases or standards (except where that is the intention).[29]

Programs designed carefully to avoid these pitfalls can be effective in encouraging the development and use of innovative technologies. Increasingly, environmental regulation has adopted technology development and diffusion as an explicit program element, especially in cases, like brownfields, where standard practice is often ineffective.

Government's involvement in developing and testing new technologies for cleanup and site assessment—and, in fact, for a broader range of environmental technologies—is something of a special case. Government itself owns many contaminated sites, including both brownfields and Superfund sites. These properties need to be cleaned up, often because of public health problems, and sometimes in preparation for privatization, as in the case of defense base closures. These facts, together with the market's attenuation for environmental technologies, support a more active government role in developing and diffusing new technologies than is the case in many other sectors.

ENCOURAGING INNOVATIVE TECHNOLOGIES IN BROWNFIELD ASSESSMENT AND CLEANUP

Innovative technologies can be encouraged in several ways, such as stimulating research and development, providing incentives for deployment, reducing barriers to adoption, and offering information on effectiveness. The Environmental Protection Agency (EPA), Department of Energy (DOE), and other agencies interested in cleanup of contaminated sites have several such programs. Most of these efforts are devoted to Superfund sites that are more contaminated (often, far more contaminated) than brownfields, and many pose problems (like radioactive waste) that are rare in brownfields. Moreover, the more acute public health threats posed by Superfund sites make them more effective technology drivers than the lesser risks and problems posed by brownfields. Still, the following government programs are relevant for both Superfund and brownfield sites.

RESEARCH AND DEVELOPMENT

EPA and DOE support research and development of alternative technologies for treatment of contaminated sites. While the focus on Superfund sites sometimes has not carried over to brownfields, this is probably not a handicap in technology development.

EPA's Office of Research and Development (ORD) conducts research on site cleanup. In 1998, for example, the Land Remediation and Pollution Control Division of the National Risk Management Research Lab examined biofiltration in order to remove volatile organic compounds (VOCs) from contaminated soils, bioventing, oil spill biodegradation, soil washing/biotreatment, acid mine drainage treatment with sulfate reducing bacteria, bioslurry reactors, composting, biopiles, and phytoremediation.[30] These programs include applied research, and bench and field testing, often at government-owned sites. Results of field testing are made available in a standardized format[31] through the Federal Remediation Technologies Roundtable.[32] Much of EPA's work on remediation is done under the auspices of the Superfund Innovative Technology Evaluation (SITE) program, funded at $6 million in fiscal 1998. The summaries of federal tests of different assessment and cleanup technologies have yielded no single finding or result, but they can provide a great deal of guidance to anyone wishing to evaluate treatment options for brownfields. These tests and demonstrations help to define the strengths and limitations of different techniques, and they provide insight into the effects of site-specific conditions, a few of which are reflected in Figure 1.

"These tests and demonstrations help to define the strengths and limitations of different techniques, and they provide insight into the effects of site-specific conditions."

The Department of Energy also conducts research, development, and engineering on assessment and remediation of contaminated sites. DOE's Office of Environmental Management (EM) funds both cleanup of DOE's contaminated sites and R&D on cleanup and assessment technologies. In 1998, EM's budget for science and technology totaled nearly $275 million, most of which went towards R&D for defense environmental remediation and waste management. While some of the defense work—e.g., on radioactive waste cleanup—is probably not pertinent to brownfields, some is. For example, a cleanup process known as In-Situ Redox Manipulation (ISRM), developed at DOE's Pacific Northwest National Laboratories in Richland, Washington, is effective in removing certain types of metal contaminants in groundwater, and several state agencies are interested in possible applications.[33]

Even a cursory survey of DOE's current research reveals millions of dollars' worth of studies aimed at developing, validating, or testing remediation and assessment technologies. Although these technologies are developed for and/or tested on DOE's own contaminated sites, many have much broader applicability.

It is difficult to pinpoint how much the federal government spends to advance technologies for soil and groundwater cleanup. Research and development projects are performed in several labs and offices throughout DOE and EPA, the major players in cleanup technology R&D. Even very strict accounting would probably still include tens, possibly into the hundreds, of millions of dollars' worth of research and development.

Other federal agencies have roles as well, especially those with contaminated facilities of their own. A 1995 report of the Federal Facilities Policy Group estimated cleanup costs for federal contaminated facilities, including those of the Departments of Energy, Defense, Interior, and Agriculture, as well as the National Aeronautics and Space Administration. Of these agencies, DOE's costs were by far the highest, accounting for 85-90 percent of the estimated total. The Department of Defense's (DOD) estimated cleanup costs were $26 billion, the second highest total of the five agencies (a more recent report[34] estimates DOD cleanup costs at $30 billion). Yet DOD's efforts may be more important than the extent of contamination and cleanup costs indicate. With the end of the Cold War, DOD closed many bases, which become available for transfer to other federal uses or private economic development.[35] The real possibility of commercial use of some contaminated sites increased the urgency for DOD to assure effective cleanups of these sites, and the department's extensive technical and scientific infrastructure made it a logical choice for developing and testing cleanup technologies.

Much of DOD's environmental R&D is conducted under the auspices of the Strategic Environmental Research and Development Program (SERDP), which the agency plans and executes together with DOE and EPA. SERDP areas include cleanup, compliance, conservation, and pollution prevention. The budget for cleanup, which is the part of SERDP most applicable to brownfield technology development, was $14.6 million in 1995 and $17.4 million in 1996. The program's mission is to develop innovative site characterization techniques, improve monitoring capabilities, and develop cost-effective remediation technologies for soil and groundwater.[36] Much of SERDP's focus is on problems specific to DOD sites, including unexploded ordinance (which is generally not a contaminant in private-sector brownfields). But SERDP provides public access to research results on site assessment, cleanup, and monitoring, and some of this information can be useful in brownfield cleanup and redevelopment.

TESTING AND VERIFICATION

Federal technology development programs are criticized routinely for stopping so far short of commercialization that the costs for the private sector to bridge the gap between research and deployment are prohibitive. In contrast, federal programs for soil and groundwater cleanup have performed well; cleanup technologies developed in or for the federal government often are tested in the field, and the results of these trials are available on paper and the World Wide Web. A 1995 EPA publication[37] summarizing the results of 38 field-scale tests of remedial technologies covered bioremediation, soil vapor extraction (SVE), thermal desorption, soil washing, in situ vitrification, and several groundwater treatment technologies. The report includes not only the technical results (type and source of contamination, media treated, degree of remediation), but also costs and duration of treatment projects—valuable information that often is lacking or unavailable from technology validations. One caution is that most of the tests were run on Superfund sites or underground storage tanks, which may provide limited guidance on treatment costs and times for less-contaminated brownfields.

DOE provides for testing and evaluation of innovative assessment and cleanup technologies through its Innovative Treatment Remediation Demonstration Program (ITRD), in cooperation with the Technology Innovation Office of EPA's Office of Solid Waste and Emergency Response. ITRD aims squarely at reducing industry's fear of new-technology failure and at speeding acceptance of new remediation approaches. The program is coordinated by Sandia National Laboratories, which puts together advisory groups of federal and state regulators, technology experts, and users in order to evaluate technologies for which cost and performance information are considered weak. Treatment studies are conducted on small, one- to two-acre sites. Examples of such technologies include bioremediation, soil washing and flushing, solvent and surfactant extraction, and in situ passive treatment. After careful review and evaluation, treatment studies and engineering evaluations are conducted. In early 1997, projects were underway at four DOE sites.[38]

SERDP provides test sites for technology demonstrations and evaluations. SERDP's National Environmental Technology Test Sites (NETTS) program allows both public- and private-sector technology developers to use any of five locations to test and evaluate innovative technologies for site characterization, cleanup, and monitoring. The five NETTS sites are McClellan Air Force Base in Sacramento; the Naval Construction Battalion Center in Port Hueneme, California; EPA's National Exposure Research Laboratory in Las Vegas; the National Center for Bioremediation R&D in Michigan; and Dover Air Force Base in Delaware. In fiscal year 1997, five demonstrations were completed and six were ongoing at the McClellan AFB, and the Michigan NETTS reported that it had provided opportunities to test advanced technologies in "site characterization, decontamination of hazardous wastes, remediation of spill and disposal sites, and the intrinsic bioremediation of fuel and chlorinated mixtures in both aquifer materials and groundwater."[39] Noting that the National Research Council identified inconsistent test information as one handicap facing potential users of innovative technologies, the NETTS facilities all report that they help provide public and private clients with reporting protocols so that technologies can be compared on a consistent basis.

Another DOD program is the Environmental Security Technology Certification Program (ESTCP). ESTCP's goal is to validate and demonstrate promising technologies that target DOD's most difficult environmental problems, including site cleanup. ESTCP is coordinated with SERDP, and program documents describe ESTCP projects as providing demonstration and validation capacity for technologies developed in SERDP.[40] ESTCP has sponsored several demonstrations of innovative assessment and cleanup technologies, mainly at military sites, and it provides overviews of certain techniques that have been used enough to assess their effectiveness under a variety of site conditions.[41]

REDUCING BARRIERS TO ADOPTION: INFORMATION

In contrast to the situation less than a decade ago, several sources of information exist on the performance and characteristics of new technologies for site assessment and cleanup. SITE and SERDP both make test and demonstration results available. In addition, EPA supports several efforts to provide information to potential vendors and users of innovative technologies.

EPA's Office of Research and Development (ORD) maintains the Alternative Treatment Technology Information Center (ATTIC), a database that contains information on biological, chemical, thermal, physical treatment, and solidification/stabilization. ATTIC is a rich database, containing a variety of information, from presentations to technical papers to fact sheets and citizens' guides. Anyone wishing to gain an acquaintance with the basics of alternative technologies would be well advised to spend some time searching ATTIC.

The Innovative Treatment Technologies (ITT) database, maintained by OSWER's Technology Innovation Office, provides comparable data on hundreds of sites. The data are from Superfund and RCRA sites, as well as DOE and DOD sites not covered by CERCLA or RCRA. The database does not allow a user to sort for brownfields specifically, but it does afford in a consistent format information on site, location, media, contaminants, and contacts. It does not furnish cost information. Both ATTIC and ITT are available at no charge from EPA, or through EPA's website.

For those who prefer paper, or who are just beginning to consider technology options, EPA also has published the *Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup* and the *Tool Kit of Information Resources for Brownfields Investigation and Cleanup*[42] Both are useful, and should probably be updated periodically. The Road Map also provides contacts for those wanting more information.

The Federal Remediation Technologies Roundtable supports an extensive database describing treatment technologies, test results, costs, and site-specific information arising from tests. The Remediation Technologies Screening Matrix and Reference Guide is a robust, large, searchable database that represents itself as "a yellow pages of remediation technologies." The database is organized such that a user can look at different technologies in order to discover how they performed at cleaning up various kinds of sites or different contaminants.

According to the report's overview,

"The unique approach used to prepare this guide was to review and compile the collective efforts of several U.S. Government agencies into one compendium document. For each of several high-frequency of occurrence types of sites, the guide enables the reader to:

- *Screen for possible treatment technologies.*
- *Distinguish between emerging and mature technologies.*
- *Assign a relative probability of success based on available performance data, field use, and engineering judgment."*[43]

One advantage of the FRTR guide is that much of the data is presented in ways that permit comparisons among different approaches. For example, most of the technology discussions contain cost data, and most of the cost data is offered on a per-unit basis. Gathering and presenting large amounts of information in consistent forms requires constant vigilance, and the FRTR database (and the agencies contributing to it) could use more work on data consistency. Nonetheless, the database is a significant step forward in the effort to provide users with a guide to selecting innovative technologies.

The Rapid Commercialization Initiative (RCI) is a federal/state/private effort to "expedite the application of new environmental technologies."[44] Participants include the Departments of Commerce, Defense, and Energy, the EPA, the Southern States Energy Board, and the Western Governors Association. RCI has sponsored demonstration projects that identify barriers to the use of new technologies and encourage removal of those barriers. Thus far, the program has sponsored ten projects, each on a different technology, and its managers hope to obtain multi-state verifications for each project.[45] Yet it is not clear that RCI has achieved significantly more rapid penetration of new technologies.

Another project supported by EPA is the Ground-Water Remediation Technologies Analysis Center (GWRTAC), which describes itself as a national environmental technology transfer center. GWRTAC maintains an extensive database of technologies for groundwater cleanup for the use of technology users or vendors, researchers, environmental consultants and contractors, investors, citizen groups, and government agencies. It offers four sets of documents: (1) peer-reviewed technology evaluations, (2) information reports on technology use, regulatory issues, and policies, (3) technology overviews, and (4) status reports on emerging technologies.[46]

A few years ago, practitioners in site remediation worried that too little information was available on innovative or emerging technologies. Now, largely due to EPA's efforts, a great deal is available. Though it is not possible to go to one source in order to make quick comparisons of the costs, time, media, contaminants, and regulatory status of all technologies, this is fairly typical of any area of technology. In brownfield remediation, one of the main problems is simply time. Especially if a site is involved in an ongoing real estate transaction, there simply may not be time to evaluate all possible technological approaches, or there is little incentive to explore innovative technologies due to time constraints. The databases and information sources, therefore, may be more useful for administrators, regulators, technology developers, consultants, and remediation contractors wishing to keep abreast of new developments, rather than site developers or owners seeking the speediest route to redevelopment.

"While many states have moved away from Superfund's standard of cleanup-to-background-levels for sites intended for industrial use, many do specify groundwater or soil contamination levels based on the property's intended use."

REDUCING BARRIERS TO ADOPTION: PERMITTING

Many brownfield cleanups require multiple permits, each of which takes time. The unpredictability and potential for long delays in the permitting processes are compounded for new technologies, with which regulators and oversight bodies are often unfamiliar. The possibility of stretching out an already lengthy process may be enough to discourage early users of an innovative technology.

Technological change has proven to be difficult to accommodate in environmental policies. While technology development and diffusion are rarely the objective of environmental regulation, their importance has grown together with an understanding that they often are the only or least costly means to achieve the goals of environmental restoration or pollution prevention.

The most effective environmental-policy tools to encourage development of new, less-polluting technologies have been those that focus on single sources of pollution with uncompromising requirements to comply with a fixed standard—so-called command-and-control solutions.[47] Some of these include harm-based standards (e.g., Superfund cleanup standards), design standards based on what a model technology might achieve, technology specifications, and outright product bans or cancellations.

These kinds of tools often are used either implicitly or de facto in brownfield cleanups. While many states have moved away from Superfund's standard of cleanup-to-background-levels for sites intended for industrial use, many do specify groundwater or soil contamination levels based on the property's intended use. In effect, this means that many states have adopted harm-based standards for brownfield cleanups. While technology specifications rarely are used formally, permitting authorities and regulators often use as yardsticks their estimation of the mitigation achievable with dig-and-haul or pump-and-treat—technological default options in brownfield cleanups. Technology specifications usually have trouble adapting to new information and technology.[48]

The effort to abridge the regulatory burden of Superfund through state voluntary cleanup programs has helped move many brownfields into development. States, however, need to realize that streamlining often is done by creating de facto presumptive remedies, which often turn into the next generation of standard approaches. Specifying presumptive remedies may be quite good at expediting the journey of a promising technology from demonstration to common practice. If, however, the objective is to promote the continual advance of technology—to create incentives for ongoing work on new technologies even while the newest generation of improved techniques are being adopted—then presumptive or streamlined approaches should be used with great caution, or in combination with incentives for innovation.

Programs aimed at acquainting regulators and permitting authorities with new technologies can encourage adoption of available new technologies without impairing the incentives for future innovation. Several of the technology demonstration/validation programs described above aim to reach permitting authorities and state and federal regulators, precisely to encourage their acceptance of new, promising technologies.

"Programs aimed at acquainting regulators and permitting authorities with new technologies can encourage adoption of available new technologies without impairing the incentives for future innovation."

Some argue that another option to encourage innovation in brownfield cleanup is to abandon CERCLA permitting and oversight procedures for brownfields. According to the Colorado Center for Environmental Management, which evaluated state cleanup programs,

> *"The enormous amount of oversight required under traditional enforcement-driven cleanup programs may itself create delays. Overworked state agencies cannot provide the detailed oversight for numerous sites in a timely manner. The NCP [National Contingency Plan], permitting, and other oversight procedures may be important at large sites with complex contamination or geology, and where potential for human exposure is high. However, for many, if not most sites, rigorous regulatory procedures may needlessly delay cleanup."*[49]

Increasingly, states have adopted risk-based standards for brownfield cleanups, which are helpful in encouraging experimentation with new approaches, especially when accompanied by streamlined permitting and approvals.

REDUCING BARRIERS TO ADOPTION: FINANCING AND LIABILITY

Only a few years ago, financing for brownfield cleanup, or any real estate transaction involving property with known contamination, was nearly unavailable. Stung by court decisions that held lenders liable for cleanup of contaminated properties acquired through default, lenders grew wary of financing transactions involving sites with potential contamination. Helping to curtail lender fears of liability were efforts by EPA, state governments, and a variety of institutions, including the Office of Thrift Supervision, the Federal National Mortgage Association, Freddie Mac (the company formerly known as the Federal Home Loan Mortgage Corporation), the Federal Deposit Insurance Corporation, and the American Society for Testing and Materials. While nontrivial risks remain in environmental finance, most lenders have access to or have developed guidelines for financing transactions involving contaminated properties; as a result, capital flows for cleanup and redevelopment have been liberated.

Despite the increase in brownfield financing, lenders generally devote little to no time evaluating technological options. Financiers rely on in-house experts and environmental consultants, generally not those retained by the prospective buyer or seller of the property at issue, in order to assess the type and degree of contamination, devise a cleanup plan, and estimate the cost of cleanup and monitoring. Their only concern with technology, in general, is that it be accepted or approved by state regulatory authorities. But state regulators approve cleanup plans, not technologies. Innovative technologies, by definition, are new, and lack an extensive record of use and evaluation; the documentation that does exist may not include sites with hydrology, geology, or contamination that are comparable to current problems.

EPA, DOE, and DOD all have information outreach programs (see above, Reducing Barriers to Adoption: Information) designed to help acquaint state regulators, vendors, and environmental consultants with new technologies. These programs, together with state and federal efforts to reduce lender liability, are probably the most effective way to encourage the use of innovative technologies.

Another approach to encouraging innovation is to soften the risk of failure. So-called soft landings or fail-soft options permit limited noncompliance while new technologies are being developed, or limit penalties for near misses.[50] This flexible approach to regulation has been tried at the Occupational Safety & Health Administration and proposed in EPA's Common Sense Initiative and RCRA rules. The debate over the effectiveness of such approaches centers on both environmental compliance and the impacts on innovation. Some analysts worry that soft landings might encourage abuse, but proponents of the approach point out that when abuse is identified, the system could default to the conventional regulatory system.[51] It is also quite plausible that a well-designed fail-soft approach could encourage technological experimentation and innovation, but to date, no independent analysis of real-world effectiveness has been done. Moreover, some analysts doubt that agencies have much to offer in terms of reduced penalties for near misses; laws usually do not provide for shades of compliance, so agencies might be able to reduce fines or extend compliance time limits, but they may have insufficient scope for tinkering with standards themselves.

NONTRADITIONAL APPROACHES TO INNOVATIVE TECHNOLOGIES AND BROWNFIELDS

Most of what is said and written about brownfield technologies has to do with techniques for assessment, cleanup, and monitoring. But there is also substantial scope for policy innovation in brownfield reuse, and much has already been done. Brownfield regulation and cleanup has been a fast-moving field recently. Five years ago, most brownfields were subject to CERCLA cleanup standards, there was little financing available for contaminated-property transactions or redevelopment, and what information existed on treatment technologies was difficult to access and allowed few comparisons of technologies' effectiveness and costs. Things have changed. EPA and the states have provided enough mitigation of lender liability that there is now more capital available to finance real-estate transactions involving brownfields. States have moved rapidly toward requiring risk-based cleanup standards rather than CERCLA's cleanup-to-background-levels standard. Still, the brownfields that have benefited most from these policy innovations are sites where the property's market value outweighs its cleanup cost. For brownfields in rural or more blighted urban areas, or any project for which the economics are not extremely strong, cleanup costs remain a problem. Increasingly, the trend is to postpone action, sometimes indefinitely, on sites that are not considered prime real estate, and for which underfunded state programs lack cleanup resources.

Another approach is to promote alternative or interim uses of brownfields. One such approach is described in Box 2, Phytoremediation and the Process of Innovation. Another idea is to use stabilized brownfields—sites that are not expected to cause unacceptably high levels of groundwater or drinking water contamination, or sites that have been capped to limit exposure to soil contamination—to provide clean power. Less contaminated brownfields sites could be used as small power generating facilities, employing advanced microturbines or relocatable photovoltaic (solar energy) installations.[52] Many brownfields are abandoned industrial or railroad sites, and so have hookups to the electric grid available. With electricity restructuring proceeding at both the state and national level, it is becoming increasingly common for non-utility power producers to be able to sell excess electricity to the grid at prevailing rates. This option is

BOX 2

Phytoremediation and the Process of Innovation

One especially promising new tool for remediation is phytoremediation, the use of plants to achieve faster natural attenuation of certain types of contaminants. Interest in phytoremediation is growing because, where it can be used, it promises much lower treatment costs. Its major drawback—long treatment periods, often measured in years—usually is not a problem for sites not involved in an immediate, short-term real-estate transaction. Municipalities often are interested in phytoremediation both to lessen contamination and to improve the appearance of brownfields. Yet phytoremediation may offer other benefits as well.

One project underway in central New York is experimenting with the use of willows to lessen persistent hydrocarbon contamination on a privately-owned site.[54] A nearby university, the State University of New York at Syracuse, had been studying the use of willow species for bioenergy—biomass fuels for conventional electricity plants, which can reduce air pollutants and greenhouse gas emissions. The project's scientists were curious to know whether the willows also might help to reduce contamination on the site, a riverine ecosystem in central New York. Using over 30 different clones[55] available from the university's experiments on biomass production, they planted the willows on the contaminated sites in summer of 1998 and are monitoring both soil contamination and tree growth/ biomass production, to see if biomass production is compatible with phytoremediation. One early concern was that tree growth might be impaired by contact with the contaminants.

So far, formal sampling has not yet been done, but in the opinions of several experts, tree growth is at least on a par with the growth of unstressed willow clones on agricultural sites—in other words, quite robust. Survival rates of the willows are also quite high. Despite the fact that planting was done somewhat late—during June and July, when soil temperatures were higher and precipitation much lower—more than 95 percent of the planted cuttings have survived. Due to the lateness of the planting, researchers irrigated the sites to assure the equivalent of at least one inch of precipitation per week, and mixed mulch with the soil to lower soil temperatures and reduce contaminant contact with roots. Site preparation was done to the standards of agricultural practice. None of these—site preparation, mulching, or irrigation—added significantly to the cost of establishing the willows, and irrigation may become a staple of phytoremediation projects to help with plant establishment. Soil sampling will be conducted next year to assess the degree and rate of remediation.

The project's goal, according to spokesman David McMillan, is to create a sustainable ecosystem, as well as to provide remediation and biomass production for electricity generation. Accordingly, the researchers have integrated grasses into the willow plantings in order to avoid creating a monoculture. The grass, it is hoped, also may help with remediation, as well as create greater ecological diversity and better habitat than the trees alone.

Although this effort is still an experiment, early results are promising, and the combination of remediation and biomass production may be replicable on contaminated properties within economical hauling distance of electric power plants, lowering the true costs of both remediation and bioenergy production. While this approach is not an answer for every brownfield, it could provide a path to remediation and beneficial reuse of many sites.

also called net metering, which allows non-utility electric power producers to, as it is often put, "run the meter backward" when they consume electricity they have produced.

While utility restructuring is far from settled, there is already a healthy stimulus to the market for independent electricity production. High peak power rates—which often exceed 30 cents per kilowatt-hour—have added urgency to many customers' search for reliable, alternative sources of electricity. For municipalities with many abandoned industrial sites on their hands, the idea of making interim use of these unattractive properties as small electric generating facilities is attractive. Reportedly, several cities (including Baltimore, Atlanta, and Chicago) are interested in using stabilized brownfields as small solar power producing facilities.

Photovoltaic (PV) electric generation is not yet economically competitive with natural-gas-fired electricity generation, or the idea presented above would probably have attracted commercial investment already. However, PVs are becoming competitive in niche applications, like producing extra power during peak electricity generation times, when commercial electricity prices are high enough that backup PV capacity can be economically attractive. For municipalities, too, being able to shave a few cents off peak power rates for everyday municipal uses may be an attractive option from a strictly fiscal standpoint.

There are probably other ways that municipalities can make brownfields that are not attractive to developers into something better than fiscal dead weight and/or urban blight. One emerging remediation technology, phytoremediation, uses plants to absorb contaminants. One possibility is to plant grass or trees on abandoned sites, not necessarily as a full-fledged cleanup measure, but to accomplish some remediation (as well as the other benefits that plants in cities provide, including lowered reflectivity, which decreases cities' tendencies to become heat islands in summer, and improved air quality) until some other disposition can be made for the property. Interim economic or public-sector uses of lightly contaminated brownfields should be explored in greater detail, especially if, as expected, cleanup and redevelopment are accomplished on more attractive properties, leaving a residual of less desirable properties strewn across urban landscapes.

ENDNOTES

[1] National Research Council, *Innovations in Ground Water and Soil Cleanup*, (Washington, D.C.: National Academy Press, 1997), chapter 1 passim, and pp. 32-4.

[2] Examples of attempts to create markets for environmental amenities, or rights to pollute, are most numerous in the implementation of the Clean Air Act. Creation of tradable emissions permits and permit markets is encouraged by the 1990 Clean Air Act Amendments, and the most prominent example is the establishment of a market for tradable allowances of SO_2 emissions. See Congress of the United States, Office of Technology Assessment, *Environmental Policy Pools: A User's Guide*, OTA-ENV-634, (Washington, D.C.: U.S. GPO, September 1995), pp. 108-113.

[3] OTA, op. cit., p. 16.

[4] National Research Council, *Innovations in Ground Water and Soil Cleanup: From Concept to Commercialization*, (Washington, D.C.: National Academy Press, 1997).

[5] Cited on http://hyperion.advanced.org/10419/pre.htm.

[6] Ibid., p. 1. The same is apparently not true of conventional soil treatment, so long as contamination is a factor only in the top few inches of soil. In such cases, excavation and landfilling or incineration of contaminated soil are effective and relatively predictable ways of dealing with contamination.

[7] For example, the title of this report: U.S. Small Business Administration, "Bridging the Valley of Death: Financing Technology for a Sustainable Future," prepared for the U.S. Environmental Protection Agency, December 1994.

[8] National Research Council, *Innovations in Ground Water and Soil Cleanup: From Concept to Commercialization*, Committee on Innovative Remediation Technologies (Washington, D.C.: National Academy Press, 1997), p. 44.

[9] "Facts about Small Business, 1997," http://www.sbalgov/ADVO/stats/fact1.html, p. 4.

[10] National Research Council, op. cit., p. 44.

[11] Interstate Technology and Regulatory Cooperation (ITRC) Work Group and Colorado Center for Environmental Management, "Case Studies of Selected States' Voluntary Cleanup/Brownfields Programs," Draft, May 19, 1997, p. v.

[12] Dan Powell, U.S. EPA, Technology Innovation Office, personal communication, July 29, 1998.

[13] See the Appendix for a brief list of innovative assessment and cleanup technologies.

[14] Other statutes can be used to establish liability for damages or cleanup as well, including state Superfunds, the Resource Conservation and Recovery Act (RCRA), and other federal and state environmental laws. OTA, op. cit., pp. 6-7.

[15] Ibid.

[16] Forest L. Reinhardt and Richard H.K. Vietor, *Business Management and the Natural Environment: Cases and Text*, (Cincinnati, OH: South-Western College Publishing, 1996, p. 2-137.

[17] ITRC, op. cit., p. iv.

[18] Environmental Financial Advisory Board, "Expediting Clean-up and Redevelopment of Brownfields: Addressing the Major Barriers to Private Sector Involvement—Real or Perceived," December 1997.

[19] ITRC, op. cit., p. 19.

[20] Environmental Financial Advisory Board, op. cit.

[21] ECOS, "EPA Draft Guidance for Developing Superfund Memoranda of Agreement Language Concerning State Voluntary Cleanup Programs," Resolution Number 97-8, September 24, 1997.

[22] ITRC, op. cit., p. 8.

[23] Ibid., p. v.

[24] Environmental Financial Advisory Board, "Expediting Clean-up and Redevelopment of Brownfields: Addressing the Major Barriers to Private Sector Involvement—Real or Perceived," 1998.

[25] ITRC, *Case Studies of Selected States' Voluntary Cleanup/Brownfields Programs*, op. cit., p. 31.

[26] Ibid., p. 28.

[27] John A. Alic, Lewis M. Branscomb, Harvey Brooks, Ashton B. Carter, and Gerald L. Epstein, *Beyond Spinoff: Military and Commercial Technologies in a Changing World*, (Boston, MA: Harvard Business School Press, 1992), p. 350-4.

[28] Steven Durlauf, "What Should Policymakers Know About Economic Complexity?" reproduced on http://www.santafe.edu/, September 13, 1997, p. 6.

[29] There are times when markets can be slow to develop without a standard. For instance, many analysts believe that the creation of ASCII was a key to the widespread acceptance of microcomputers. In such circumstances, government action to create standards for interoperability may be appropriate.

[30] These programs are described on http://www.epa.gov/ORD/NRMRL/lrpcd/tdb/.

[31] U.S. Environmental Protection Agency, Department of Defense, Department of Energy, and Department of Interior, "Guide to Documenting Cost and Performance for Remediation Projects," March 1995.

[32] U.S. Environmental Protection Agency, Department of Defense, Department of Energy, and Department of Interior, "Abstracts of Remediation Case Studies," March 1995.

[33] Steve Kidney, "System Shows Promise for Simpler Groundwater Cleanup," *The Brownfields Report*, Thursday, August 13, 1998, p. 3.

[34] The Council of the Strategic Environmental Research and Development Program, *Annual Report to Congress—Fiscal Year 1997*, March 1998. Posted on http://www.serdp.gov/councilrpt/CNCLRPTWP97.PDF.

[35] *Improving Federal Facilities Cleanup: Report of the Federal Facilities Policy Group*, October 1995, posted on http://www.epa.gov/swerffrr/octscan.htm.

[36] Posted on http://www.serdp.gov/overview/thr_area.html.

[37] U.S. Environmental Protection Agency, Department of Defense, Department of Energy, and Department of Interior, "Abstracts of Remediation Case Studies," March 1995.

[38] See http://www.em.doe.gov.itrd/info.html.

[39] The Council of the Strategic Environmental Research and Development Program, *Annual Report to Congress—Fiscal Year 1997*, posted on http://www.serdp.gov/councilrpt/CNCLRPTWP97.PDF.

[40] See http://www.estcp.org/geninfo/index.htm.

[41] See, for example, ESTCP, "Air Sparging: Technology Transfer and Multi-Site Evaluation," on http://www.estcp.org/projects/cleanup/remed/199808.htm.

[42] United States Environmental Protection Agency, *Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup*, EPA-542-B-97-002 (Washington, DC: U.S. EPA, 1997); and United States Environmental Protection Agency, *Tool Kit of Information Resources for Brownfields Investigation and Cleanup* EPA-542-B-97-001 (Washington, D.C.: U.S. EPA, 1997).

[43] http://www.frtr.gov/matrix2/.

[44] Posted on http://rci.gnet.org/.

[45] "Memorandum of Understanding to Implement the Rapid Commercialization Initiative: An Interagency and Interstate Partnership," on http://rci.gnet.org/scripts.EAS>DLL?SubSystemD=5&ComponentID=176.

[46] GWRTAC's website offers all the reports described above. See http://www.gwrtac.org/html.

[47] Congress of the United States, Office of Technology Assessment, *Environmental Policy Tools: A User's Guide*, OTA-ENV 634 (Washington, D.C.: U.S. GPO, September 1995), p. 19.

[48] OTA, *Environmental Policy Tools*, op. cit., pp. 27-33.

[49] Gary G. Broetzman, Paul W. Hadley, and Nettie J. Rosenthal, J.D., for the Interstate Technology and Regulatory Cooperation Work Group and Colorado Center for Environmental Management, *Case Studies of Selected States' Voluntary Cleanup/Brownfields Programs*, draft, May 19, 1997, p. 8.

[50] Congress of the United States, Office of Technology Assessment, *Industry, Technology and the Environment: Competitive Challenges and Business Opportunities*, OTA-ISC-586 (Washington, D.C.: U.S. GPO, January, 1994), p. 277.

[51] Ibid.

[52] The material on photovoltaic sites as interim uses for brownfields was provided by Scott Sklar, executive director, Solar Energy Industries Association, personal communication, September 16, 1998.

[53] Personal communication with Dave Dunham, executive director, Central Massachusetts Economic Development Authority, November 30, 1998.

[54] Information on this project was given by David McMillan, scientist, SUNY-Syracuse and ARM Group, Inc., in personal communication with NEMW staff, December 8, 1998.

[55] Willows, like aspens and some other hardwoods, reproduce in several ways, including sprouting from the roots of established trees. Offspring that have grown from the roots of existing trees, or from cuttings, are called clones, since their genetics are identical to their parents'. A single clone of willow or aspen can cover many acres.

Innovative Treatment Technologies for Contaminated Soil, Sediment, and Sludge

Technology	*Description*	*Contaminants Treated*	*Overall Cost**	*Time Require ments*	*Resource Require-ments*	*Status*
			In Situ Treatments**			
Biodegradation	The use of microorganisms to decompose chemical compounds, which would otherwise persist for a long time in the environment.	Most effective on volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), fuels, explosives; less effective on inorganic compounds.	~$100/cubic meter.	Average	Operation and maintenance (O&M) intensive	Available
Enhanced Bioremediation	The activity of naturally-occurring microbes is stimulated by circulation of water-based solutions through contaminated soils to enhance biological degradation. Nutrients, oxygen, or other amendments may be used to enhance treatment.	Effective in treating petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. Especially effective in treating low level residual contamination in conjunction with source removal.	$30-100/cubic meter of soil.	May take several years (slower than average)	NA	Available
Bioventing	Adding oxygen to soil in the vadose zone (above the water table where pores and crevices are not saturated with water) to stimulate microbial activity for bioremediation.	Most effective on VOCs, SVOCs, and fuels; less effective on inorganic compounds.	$10-$70/cubic meter.	Slower than average	Neither operation and maintenance intensive nor capital intensive	Available
Land Treatment	Contaminated surface soil is treated in place by tilling to achieve aeration, and if necessary, by addition of amendments. Periodic tilling to aerate the waste enhances the biological activity.	Most successful in treating petroleum hydrocarbons and other less volatile, biodegradable contaminants. Diesel fuel, No. 2 and No. 6 fuel oils, JP-5, oily sludge, wood-preserving wastes (PCP, PAHs, and creosote), coke wastes, and certain pesticides have been treated successfully.	$30-$70/cubic meter.	Average to slower than average.	NA	Available
Natural Attenuation	Natural processes — such as dilution, dispersion, volatilization, biodegradation, adsorption, and chemical reactions with soil materials — are allowed to reduce contaminant concentrations to acceptable level.	Can be used to treat VOCs, SVOCs, and fuels on a site-specific basis, depending on degree of contamination, geology, and treatment of residual contaminants (e.g., heavy metals).	Usually low, though there are costs for modeling, containment, sampling and sample analysis (potentially extensive).	Usually very slow	Usually neither O&M nor capital intensive	Available, though little guidance exists on use
Phytoremediation	Use of plants to remove, transfer, stabilize, and destroy contaminants in soil and sediment.	May be applicable for the remediation of metals, pesticides, solvents, explosives, crude oil, polychlorinated aromatic hydrocarbons (PAHs), and landfill leachates.	Expected to be low.	Slower than average	NA	Under testing in SITE program
Electrokinetic Separation	Use of electrochemical and electrokinetic processes to desorb, and then remove, metals and polar organics.	Target contaminants are heavy metals, anions, and polar organics.	Little available information; indications of $50/cubic meter and up.	NA	NA	Few trials in the United States; more in Europe
Soil Flushing	Use of chemical amendments and fluid pumping to mobilize and recover contaminants. May also use surfactants to decrease surface tension of contaminants (NAPLs) or cosolvents to increase solubility of NAPLs.	Target contaminant group is inorganics, including radioactive contaminants. Can be used to treat VOCs, SVOCs, fuels, and pesticides, but may be less cost-effective than alternatives.	Varies widely depending on amendment; $25-$250/cubic meter reported.	Short to medium term	Operation and maintenance intensive	Pilot

Technology	*Description*	*Contaminants Treated*	*Overall Cost**	*Time Requirements*	*Resource Requirements*	*Status*
Soil Vapor Extraction (SVE)	Physical separation of contaminants by creating a vacuum in soil. SVE is the most frequently used innovative treatment. May be used in situ or ex situ.	Target contaminant groups are VOCs and some fuels.	$10-$50/cubic meter, plus possible costs of water treatment and off-gas treatment.	Average	Operation and maintenance intensive	Available
Thermally Enhanced Soil Vapor Extraction	SVE can be enhanced by application of heat (generated by steam, hot air, radio waves, microwaves, or electrical resistance) to increase contaminant volatility	Target contaminant group is SVOCs.	$30-$130/ cubic meter	Faster than average	O&M and capital intensive	Available
Fracturing	Cracks are developed by fracturing beneath the surface in low permeability and over-consolidated sediments to open new passageways that increase the effectiveness of many in-situ processes and that enhance extraction efficiencies. Common techniques include pneumatic fracturing, blast-enhanced fracturing and Lasagna™ process.	Fracturing is applicable to the complete range of contaminant groups with no particular target group.	$9-$13/metric ton for pneumatic fracturing. Cost for Lasagna™ is $180-$200/ metric ton for 1-year treatment; $110-$130/metric ton for 3-year treatment.	Varies	NA	Limited availability
Solidification/ Stabilization/ Containment	This umbrella covers a wide range of techniques to decrease the mobility of contaminants in water. Techniques include removal of water, enhanced sorption with reactive barriers, precipitation/ coprecipitation, lime addition, removal of contaminants through passive/reactive barriers, use of pozzolonic (cement-like) barriers to decrease soil permeability and bond with contaminants, and the use of low-permeability barriers (slurry walls, sheet pile walls, grout walls) to prevent contaminant transport. May be used in situ or ex situ.	Target contaminant group is generally inorganics, including radionuclides.	Wide variability depending on technique and contaminant; reported costs from $25/cubic meter to >$300/cubic meter.	Faster than average	Capital intensive	Available
Vitrification	Combining contaminated soil with amendments needed to form a glass when melted, and melting. Glass is impermeable and relatively stable. Can be used in situ or ex situ.	Most effective on inorganic contaminants; effective on VOCs, SVOCs, and fuels.	More expensive than average.	Faster than average	Both O&M and capital intensive. Requires large amounts of energy.	Pilot
		Ex Situ Treatments				
Solar Detoxification	Destroying contaminants by photochemical and thermal reactions using the ultraviolet energy in sunlight.	Target contaminant group is VOCs, SVOCs, solvents, pesticides, and dyes. The process also may remove some heavy metals from water.	NA	Field trials were rapid (e.g., four months)	NA	Pilot
Composting	Contaminated soil is excavated and mixed with bulking agents and organic amendments such as wood chips, hay, manure, and vegetative wastes.	Biodegradable organic compounds, explosives, and PAHs.	Variable depending on technique and contaminant. $190-$290/ cubic yard reported.	NA	NA	Available

Technology	Description	Contaminants Treated	Overall Cost*	Time Requirements	Resource Requirements	Status
Chemical Oxidation or Thermal Reduction	Use of chemicals that oxidize or reduce (add or remove oxygen from, respectively) contaminants in order to destroy them.	Target contaminant group for chemical redox is inorganics. The technology can be used but may be less effective against nonhalogenated VOCs and SVOCs, fuel hydrocarbons, and pesticides.	$190-$660/ cubic meter.	Faster than average	Neither O&M nor capital intensive	Available
Substitution (dehalogenation)	Use of organic chemical reactions to convert contaminants into less toxic compounds, typically by replacing halogen.	Target contaminant groups are halogenated SVOCs and pesticides. Dehalogenation is one of the few processes that has been successfully field tested in treating PCBs.	$220-$550/ metric ton (exclusive of excavation, refilling, residue disposal, or analytical costs).	Inadequate data	O&M and capital intensive to inadequate data	Few full-scale tests
Landfarming	Contaminated soil, sediment, or sludge is excavated, applied into lined beds, and periodically turned over or tilled to aerate the waste.	Most successful in treating petroleum hydrocarbons.	Pretreatment costs $25,000-$50,000; $100K - $500K for pilot or field test; <$75/ cubic yard to prepare bed.	NA	NA	Available
Fungal Degradation	The use of white rot fungus to biodegrade specific contaminants, including lignin (e.g. Kraft pulping wastes). Can also be used in situ.	Can remediate predominant conventional explosives: TNT, RDX, and HMX. White rot fungus has the potential to degrade and mineralize other recalcitrant materials, such as DDT, PAH, PCB, and PCP2-4. Laboratory testing on lignin, certain PAHs, DDT, TCDD, and PCBs.	Estimated at $98/cubic meter.	Slower than average	Opertaion and maintenance intensive	Pilot
Slurry Phase Biological Treatment	An aqueous slurry is created by combining soil, sediment, or sludge with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the soil contaminants.	Successfully used to treat explosives, petroleum hydrocarbons, petrochemicals, solvents, pesticides, wood preservatives, and other organic chemicals.	$130-$200/ cubic meter for slurry treatment; $160-$210/cubic meter when off-gas treatment is added.	Can be fast	NA	Available
Soil Vapor Extraction	A vacuum is applied to a network of above-ground piping to encourage volatilization of organics from the excavated media. The process includes a system for handling off-gases.	VOCs.	$10-$50/cubic meter, plus pilot testing.	12-36 months for a typical site	Neither O&M nor capital intensive	Available
Solvent Extraction	Use of solvents to separate or remove organic contaminants from wastes, soils, sludges, and sediments.	Primarily used for organic contaminants such as PCBs, VOCs, halogenated solvents, and petroleum wastes.	$110-$440/ metric ton.	Longer than average	Both O&M and capital intensive	Available
High Temperature Thermal Desorption	Removal of VOCs and SVOCs from soil by transfer to gas phase. Vaporized contaminants are captured and destroyed.	Most effective on SVOCs, PAHs, PCBs, and pesticides.	$45-$330/ metric ton.	Faster than average	Both O&M and capital intensive	Available
Low Temperature Thermal Desorption	Same as above.	Most effective on nonhalogenated VOCs and fuels.	$45-$330/ metric ton.	Faster than average	Both O&M and capital intensive	Available
Hot Gas Decontamination	Raising the temperature of contaminated equipment or material for a specified period of time. The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants.	Applicable to process equipment requiring decontamination for reuse; also to explosive items, such as mines and shells (after removal of explosives), or scrap material contaminated with explosives.	Varies with the amount and type of material being treated.	Faster than average	Both O&M and capital intensive	Available

Technology	*Description*	*Contaminants Treated*	*Overall Cost**	*Time Requirements*	*Resource Requirements*	*Status*
Incineration	Burning contaminated media to destroy hazardous waste.	Effective on explosives and hazardous wastes, particularly chlorinated hydrocarbons, PCBs, and dioxins.	$220-$1,110/ metric ton for off-site incinerators; $1,650-$6,600 for soils contamina-ted with PCBs or dioxins.	Faster than average	Both O&M and capital intensive	Available
Open Burn/ Open Detonation	Explosives or munitions are destroyed by self-sustained combustion ignited by an external source.	Explosives, VOCs, SVOCs, fuels, and inorganic contaminants.	NA	Less than average	Both O&M and capital intensive	Available
Chemical Extraction	Waste-contaminated soil and extractant are mixed, dissolving the contaminants. Contaminants and extractant are separated for treatment and further use.	Effective in treating organic contaminants such as PCBs, VOCs, halogenated solvents, and petroleum wastes. Also applicable for the separation of the organic contaminants in paint wastes, synthetic rubber process wastes, coal tar wastes, drilling muds, wood-treating wastes, separation sludges, pesticide/ insecticide wastes, and oily waste.	$110-$440/ metric ton.	NA	NA	Available
Pyrolysis	Chemical decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.	Target contaminant groups are SVOCs and pesticides. The process is applicable for the separation of organics from 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 waste.	~$300/metric ton.	Faster than average	Both O&M and capital intensive	Limited availability
Vitrification	(see in situ treatments, above)					

Sources: U.S. Environmental Protection Agency, *Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup*, Office of Solid Waste and Emergency Response, EPA-542-B-97-002, pp. B-1 – B-2; http://windows.ivv.nasa.gov/glossary/; http://www.scana.com/sce%26g/business_solutions/technology/estwwrf.htm; National Research Council, Committee on Innovative Remediation Technologies, *Innovations in Ground Water and Soil Cleanup: From Concept to Commercialization*, (Washington, D.C.: National Academy Press, 1997), pp. 90-5; http://www.frtr.gov/matrix2/section1/toc.html;

*Cost figures exclude costs of testing, assessment, and monitoring, except where noted.

**In situ refers to wastes being treated on-site. Ex situ refers to wastes being taken off-site and treated.

APPENDIX 2

Glossary

absorption	the passage of one substance into or through another
adsorption	the adhesion of molecules to each other
aromatics	organic compounds that contain six-carbon ring structures, e.g., creosote, toluene, and phenol
BTEX	benzene, toluene, ethylbenzene, and xylene—volatile aromatic compounds typically found in petroleum products
DNAPL	dense non-aqueous phase liquids. DNAPLs are organic substances that are relatively insoluble in water and more dense than water.
dioxin	any of a family of compounds known chemically as dibenzo-p-dioxins. They are typically released during combustion.
ex situ	off site; excavated or removed
heavy metal	refers to a group of toxic metals including arsenic, chromium, copper, lead, mercury, silver, and zinc
herbicide	chemical pesticide designed to control plants
hydrocarbon	organic compound containing only hydrogen and carbon, often found in petroleum, natural gas, and coal
hydrogen sulfide	a gas emitted during decomposition of organic compounds
inorganic compound	a compound generally not containing carbon atoms, tending to be soluble in water, e.g., various acids, potassium hydroxide, metals
insecticide	a pesticide used to kill or control insects
in situ	on-site, unexcavated
methane	a colorless, nonpoisonous, flammable gas created by anaerobic decomposition (decomposition without oxygen) of organic compounds
NAPL	non-aqueous phase liquid. NAPLs are organic substances that are relatively insoluble in water and less dense than water
pesticide	substance intended to prevent or mitigate infestation by pests, plants, or animals
phenols	a group of organic compounds that are byproducts of petroleum refining, tanning, and textile, dye, and resin manufacturing
PCBs	polychlorinated biphenols, or a group a toxic, persistent chemicals, often used in voltage electrical transformers, or generated by metal degreasing, printed circuit board cleaning, gasoline, and wood preservation
PAH	polynuclear aromatic hydrocarbon, or a chemical compound countaining more than one fused benzene ring. Commonly found in petroleum fuels, coal products, and tar
solvent	a substance, usually liquid, that is able to dissolve or disperse other substances
SVOC	semi-volatile organic compound, or substances primarily composed of carbon and hydrogen, with boiling points higher than 200°C
VOC	volatile organic compound, belonging to a group of carbon-containing compounds that evaporate readily at room temperature. Examples: trichloroethylene, BTEX
volatilization	transfer from aqueous or liquid phase to gas phase

Sources: U.S. Environmental Protection Agency, *Tool Kit of Information Resources for Brownfields Investigation and Cleanup,* EPA-542-B-97-001, (Washington, DC: U.S. GPO, no date).