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Cleaning Up the Nation's Waste Sites:

Markets and Technology Trends

1996 Edition

Executive Summary

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington, D.C. 20460

NOTICE

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FOREWORD

Over the next several decades, federal, state, and local governments and private industry will commit billions of dollars annually to clean up sites contaminated with hazardous waste and petroleum products. This planned investment will result in a continuing demand for site remediation services and technologies that provide better, faster, cheaper environmental cleanup. The purpose of this report is to provide technology vendors, developers and investors, and government officials with improved information on the demand for cleanup services so that they may better identify business opportunities and plan technology research and development efforts. EPA believes that more readily available information on the cleanup market will further the development and use of new techniques for site remediation.

The study describes the future demand for remediation services in all of the major cleanup programs in the U.S., including Superfund, Resource Conservation and Recovery Act (RCRA) corrective action, underground storage tanks, state programs, and federal agencies such as the Departments of Defense and Energy (DOD and DOE). The study updates and expands a 1993 analysis that brought together for the first time valuable information on site characteristics, market size, and other factors that affect the demand for remediation services and technologies in these programs. In addition to providing updates of data in the original version, this report includes significant new information on cleanup needs related to underground storage tanks, RCRA corrective actions, and sites administered by DOD, DOE, and other federal agencies. It identifies several technology gaps, and highlights technology development priorities set by public and private sector problem owners.

Comments or questions concerning this report may be directed to the U.S. EPA, Technology Innovation Office (5102G), 401 M Street, SW, Washington, DC 20460, (703) 603-9910.

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EXECUTIVE SUMMARY

Introduction

Over the next several decades, federal, state, and local governments and private industry will commit billions of dollars annually to clean up sites contaminated with hazardous waste and petroleum products. This commitment will result in a continuing demand for site remediation services and technologies. This report was prepared to aid those who are developing and commercializing new technologies to meet the future cleanup demand. It provides an overview of the market to help industry and government officials develop research, development, and marketing strategies.

This report updates and expands a 1993 analysis that brought together for the first time valuable information on site characteristics, market size, and other factors that affect the demand for remediation services.[a] As with the previous report, the focus of this study is on the potential future applications of remediation technologies. To provide a realistic estimate of expected contracting opportunities, the demand estimates are limited to remaining cleanup work and do not include projects that are underway or completed. While the report considers a broad range of remediation services required in the future, its purpose is to provide insight into the potential application of new treatment technologies.

The national cleanup market is comprised of the following seven segments:

- National Priorities List (Superfund)
- Resource Conservation and Recovery Act (RCRA) Corrective Action
- Underground Storage Tanks (UST)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Other Federal Agencies
- States and Private Parties (including brownfields)

Most of the data used for this report are from federal databases and published sources. Some of these sources are current through fiscal years (FYs) 1994 and FY 1995, while others are current through FY 1996. Many sites are still undergoing investigation and engineering analyses, and data availability differs from one market segment to another. In addition to providing updates of data in the 1993 analysis, this report includes significant new information on cleanup needs related to RCRA corrective actions, and sites administered by DOD, DOE, and other federal agencies.

[a] U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office, *Cleaning Up the Nation's Waste Sites: Markets and Technology Trends*, EPA 542-R-92-012, April 1993.

Market Size

This section describes the estimated size of the market for contaminated site remediation services in terms of the "remaining" number of sites that require cleanup and the "remaining" cost of these cleanups. Sites where cleanup is completed or ongoing are excluded in this definition of the market. Under the current requirements of federal and state regulations, the remediation of over 217,000 sites in the seven market segments will cost about $187 billion, in 1996 dollars. The estimated time to complete most of these cleanup programs ranges from 10 to 30 years, while others, such as DOE, will take considerably longer. In addition, monitoring and groundwater treatment programs may continue for longer periods. Many of the sites to be remediated in the different programs contain similar types of contamination. In most programs, about two-thirds of the sites have contaminated soil or groundwater, or both, and contain volatile organic compounds (VOCs). Metals and semivolatile organic compounds (SVOCs) are most prevalent at Superfund and DOD sites, although they also are present at many of the sites in the other programs.

Over 217,000 contaminated sites in the U.S. still require remediation under current state and federal regulations.

The reliability of the estimates in this report differs from one market segment to another because of the availability of data, and because each of the seven programs is at a different stage of development. Some programs, such as Superfund, UST, and DOD, are well into the actual cleanup of contaminated properties. Other programs, such as DOE, have significant numbers of sites that are not yet fully characterized. In addition, definitions of basic terms such as "sites," "facilities," "installations," and "operable units" differ among the programs. Consideration of the narrative explanations and footnotes in the exhibits is necessary to fully understand the implications of the estimates.

Number of Sites

Almost half a million sites with potential contamination have been reported to state or federal authorities over the past 15 years. Of these, about 217,000 still require remediation (Exhibit 1). Almost 300,000 other sites were either cleaned up or were found to require no further action. Regulatory authorities have identified most of the contaminated sites. Nevertheless, new ones continue to be reported each year, but at a declining rate. The "estimated year of completion" shown in the exhibit is approximately the year in which almost all of the contamination will be remediated, according to current plans or agency estimates. The definitions of sites and facilities differ somewhat from one market segment to another. In this report, the term "site" is used to indicate an individual area of contamination, which can be small or large. The terms "facility" and "installation" identify an entire tract, including all contiguous land within the borders of a property. A "facility" may contain one or more contaminated areas or "sites." The status of the sites to be remediated in each market segment is discussed below.

Regulatory authorities have identified most hazardous waste sites.

Exhibit 1: Estimated Number of Sites to be Remediated

Market Segment	Sites Remaining to be Remediated	Estimated Year of Completion	Explanation
Superfund (NPL)	547	Not available	The number of sites includes non-federal proposed and final National Priorities List (NPL) sites that still required at least one further remedial action (RA), as of September 30, 1996. The NPL also includes 124 federally owned sites with future remedial actions planned. In addition to currently listed sites, EPA expects to add up to 30 sites to the NPL each year for the next several years.
RCRA, Corrective Action	3,000	2025	The number of sites represents the middle of a range of 2,600 to 3,700 from two EPA studies of all corrective action facilities that will require cleanup. The year of completion estimate is an assumption used by EPA in developing the cost estimates. It includes 30 years to complete construction. An estimated 128 years is required for monitoring and groundwater treatment. RCRA corrective action costs related to large federal facilities are included in the DOD, DOE, and civilian federal agencies market segments below.
RCRA, UST	165,000	Not available	The underground storage tank site cleanup market may be underestimated because sites where "cleanups are initiated" are not included, but some of these sites may not yet have designated cleanup contractors.
DOD	8,336	2015	The year of completion estimate is for the installation with the longest cleanup period.
DOE	10,500	2070	DOE has fully characterized about 46% of the sites, and may have completed the evaluation or cleanup of a few hundred sites. The year of completion estimate does not include cleaning up wastes for which no proven cleanup technology currently exists, such as contamination at nuclear test sites and much of the groundwater that needs to be remediated. The estimates also are based on the assumption that there will be a greater emphasis on containment than on treatment and other remediation strategies.
Civilian Federal Agencies	> 700	Varies	The number represents number of facilities, and a facility may contain one or more sites. The year of completion estimates vary among the agencies.
States	29,000	Varies	The number of sites represents sites needing attention, which may not all need remediation. The year of completion estimates vary among the states.
TOTAL	217,083		The total represents sites requiring cleanup, and excludes sites where cleanup work is ongoing or complete.

- The 547 non-federal NPL sites that require one or more future remedial actions (RAs) make up a relatively well-defined market for remedial technologies. These sites contain an estimated 33 million cubic yards of soil. The NPL also includes 124 federally owned sites with future RAs planned. These sites are included in the market estimates for federal agencies. EPA has recently implemented reforms designed to accelerate the assessment and cleanup of Superfund sites. Until the results of these reforms are evaluated, EPA cannot estimate when the remediation of currently listed and proposed NPL sites will be completed.

- EPA estimates that between 2,600 and 3,700 of the regulated hazardous waste treatment, storage, and disposal facilities (TSDFs) eventually will require remediation under the RCRA corrective action program. For this report, a middle value of 3,000 sites is used. The number of sites to require remediation is less than half of the approximately 6,200 TSDFs that currently operate or have operated. Although EPA has not estimated the time to complete this cleanup, it assumes that most of the construction would be completed by about 2025 and that monitoring and groundwater treatment could continue for 128 years.

- EPA estimates that at least 165,000 UST sites, containing at least 31 million cubic yards of soil and debris, require cleanup under the RCRA underground storage tank regulations. This estimate includes 65,000 confirmed releases that have not yet been cleaned up plus 100,000 projected releases. The estimate may understate the actual market because it does not include all sites without designated cleanup contractors. UST sites average an estimated 2.7 tanks per site, although the number varies widely from one site to another. Although USTs account for 76 percent of all future cleanup sites, they are typically the smallest and least costly to remediate.

Although USTs account for 76% of all cleanup sites, they are typically the smallest and least costly to remediate.

- DOD estimated that, as of September 1995, 8,336 sites on 1,561 installations will require remediation of contaminated materials. DOD has not yet selected contractors for most of these sites. The sites are distributed almost evenly among the Air Force, Army, Navy, and formerly used defense sites (FUDS). Of the 8,336 sites that need remediation, 3,705 (44 percent) are in six states: California, Alaska, Maryland, Florida, Texas, and Virginia. DOD estimates that all of these sites will be cleaned up by 2015. Of all DOD installations, including those where remedial action has begun, 130 are on the NPL. DOD has been placing greater emphasis on evaluating or cleaning up properties that are to be transferred to other government or private uses.

Federal and state agencies have increased their emphasis on cleaning up sites needed for the closure or reassignment of government facilities or economic development.

- DOE has identified about 10,500 contaminated sites at 137 installations and other locations that require some remediation, and the number may grow as assessment and characterization activities continue. Twenty-five DOE installations and other locations in 15 states are on the NPL. About 70 percent of the value of the remediation work is expected to be at five installations: Rocky Flats Environmental

Technology Site, Colorado; Idaho National Engineering Laboratory, Idaho; Savannah River Site, South Carolina; Oak Ridge Reservation, Tennessee; and Hanford Reservation, Washington. DOE expects to have all its sites cleaned up by 2070, although monitoring and groundwater treatment programs may continue beyond that period.

- As of April 1995, over 700 facilities, distributed among 17 civilian federal agencies (non-DOD and non-DOE), were potentially in need of remediation. The term "facility" identifies an entire tract, including all contiguous land, that is the responsibility of the subject agency. A facility may contain one or more contaminated areas or "sites." Because investigations of many of these facilities are not complete, the exact number of facilities and sites to be remediated has yet to be determined and reported to EPA. The Department of Interior (DOI), Department of Agriculture (USDA), and National Aeronautics and Space Administration (NASA) together account for about 70 percent of the civilian federal facilities that potentially need remediation. The estimated year of completion varies from one agency to another, with the longest period, 50 years, reported by the Department of Agriculture.

Interest has grown in the redevelopment of brownfield sites. EPA has awarded grants for 76 projects, as of October 1996.

- Based on data provided by the states in 1995, EPA has estimated that about 29,000 sites listed in state files require some action beyond a preliminary assessment. However, the actual number of sites that will need remediation and the extent of contamination at these sites is largely unknown, since some of these data are derived from preliminary assessments. In addition, the U.S. General Accounting Office (GAO) estimated that there are between 130,000 and 450,000 "brownfield" sites, although the number that will require remediation is unknown. Brownfields are abandoned, idle, or under-used industrial and commercial facilities where real or perceived environmental contamination may be hampering expansion or redevelopment. The cleanup of most of these sites will be the responsibility of the property owners. Recently, interest in the redevelopment of potentially contaminated sites has grown. As of October 1996, EPA had awarded grants to support the evaluation and cleanup of 76 brownfield sites and plans to award additional grants in 1997

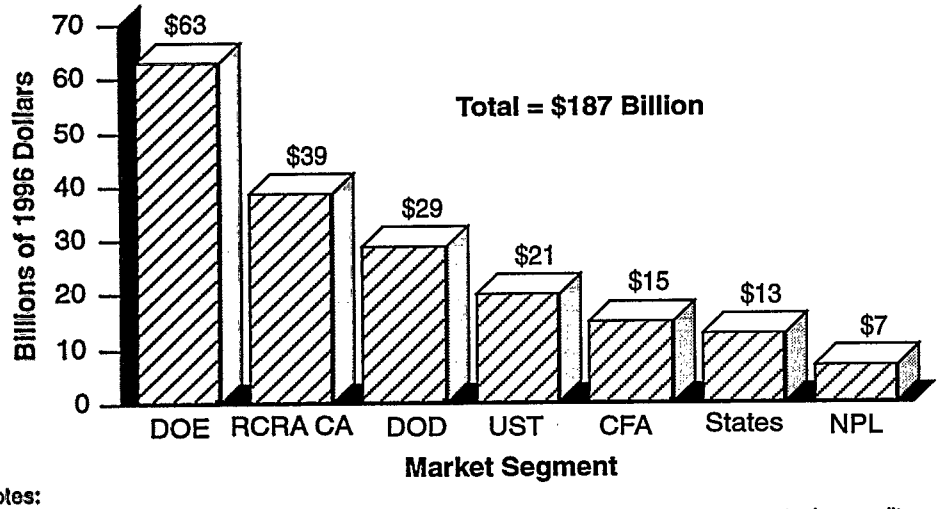
Estimated Cleanup Costs

Under current regulations and cleanup goals, the cleanup of all known sites will cost $187 billion, in 1996 dollars, and will take at least several decades to complete.

The estimated cost for all future work to clean up the 217,000 sites is about $187 billion, in 1996 dollars (Exhibit 2). Because this estimate does not include inflation for future years, the amount expended probably will be higher than $187 billion. This estimate represents the midpoint of a range that results from uncertainty regarding the extent and type of contamination at many sites, and the kind of cleanup methods that will be used.

Although most of the activities underlying this cost estimate are for remedial action, they also include some site assessment and administrative work, where costs are not reported separately. As a cleanup program matures, a greater portion of the funding shifts from site assessment and investigation to actual cleanup.

Exhibit 2: Estimated Remaining Remediation Cost in 1996 Dollars



Notes:

- Because these costs do not include inflation over the life of the cleanup programs, actual expenditures ultimately will be greater.
- These estimates are based on assumptions and rationale explained in the text.
- Cost for remedial action at NPL sites does not include: federal facilities, site assessments and studies, designs, operations and maintenance, long-term response actions, removals, site management, administrative costs (*e.g.*, payrolls), other federal agency support (*e.g.*, ATSDR, NIEHS), oversight of PRP-lead cleanups, and enforcement activities.
- Environmental restoration accounts for 28% of the $227 billion life-cycle cost DOE has estimated for all environmental management activities at its facilities. The other 72% of the costs are for activities listed in footnote b of the text.

The cost estimate for each market segment is explained below:

- The future remedial action cost for currently listed and proposed NPL sites not owned by the federal government (non-federal) from the end of FY 1997 onward, is estimated to be $6.7 billion. This estimate is based on an estimated average cost of $10 million per Fund-lead remedial action and $8.5 million for private party-lead sites. About 70 percent of site cleanups are the responsibility of private parties. The NPL site cost estimate does not include costs for site assessments and studies, designs, operation and maintenance, long-term response actions, removals, site management, administrative costs such as payrolls, other federal agency support, oversight of potentially responsible party (PRP)-lead cleanups, and enforcement activities. The estimated costs of cleaning up federal facility NPL sites are included under the other market segments below.

- Under current regulations, the cost of corrective action for soil and groundwater for RCRA characteristic or listed waste will be $38.8 billion, or an average of $14.9 million per facility, in 1996 dollars. This cost estimate is based on a regulatory impact analysis (RIA) prepared in 1993. Approximately 89 percent of this amount will be incurred by privately-owned facilities and the remaining 11 percent by federal

facilities. This estimate does not include costs for the very large DOD and DOE facilities. However, since it includes costs for some smaller ones, there is some overlap with the costs estimated for DOD and DOE below. Roughly half of the total cost of corrective action will be incurred by slightly more than 10 percent of the facilities that require cleanup. The program life-cycle-costs are likely to be lower under regulations now being developed than were estimated in the 1993 RIA, because implementation of the corrective action program has been shifting toward more risk-based cleanups. In addition, program costs in the near term will likely be lower than previously estimated, because of the emphasis on initial efforts to stabilize the site.

- The remaining UST cleanup market could reach $20.6 billion, or an average of $125,000 per UST site. This estimate does not include costs related to replacing, testing, or upgrading tanks, pipes, and related equipment. Previous studies indicate that the remediation portion of the cost to clean up one UST site ranges from $2,000 to over $400,000.

- DOD estimates that the cost of completing the remaining remediation work at all DOD sites from FY 1997 onward will be over $28.6 billion, or over $3.4 million per site, distributed as follows: Army $10.6 billion; Air Force $7.4 billion; Navy $5.6 billion; Defense Logistics Agency (DLA) $0.4 billion; Defense Nuclear Agency $0.1 billion; and FUDS $4.5 billion. While most past DOD expenditures for restoration have gone for site investigation and analysis, most future funds will be used for cleanup. DOD's cleanup budget for FY 1997 is $2.1 billion.

DOE and DOD, combined, account for one-half of the total cleanup market.

- DOE estimates that environmental restoration of its properties will cost $63 billion and take about 75 years.[b] The estimates do not include the cost of cleaning up wastes for which no proven cleanup technology currently exists, such as wastes at nuclear test sites and much of the groundwater contamination the agency is responsible for addressing. The estimates also are based on the assumption that there will be greater emphasis on containment than on treatment and other remediation strategies. Seventy percent of the total estimated cost of environmental management activities over the 75-year period will be expended at the five major installations listed in the previous section. These costs include those for all environmental restoration required under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), RCRA, other federal statutes, and state laws. DOE's FY 1997 restoration budget is $2.1 billion, and is expected to decline gradually until the program is substantially complete in 2070.

- The $15 billion estimated cost for the cleanup of about 700 civilian federal facilities is based on an extrapolation of life-cycle-costs

[b] Environmental restoration accounts for 28 percent of the $227 billion life-cycle-cost DOE has estimated for all environmental management activities at its facilities. The other 72% of DOE's environmental management costs are for the following types of activities: waste management, nuclear material and facility stabilization, national program planning and management, landlord activities, and technology development.

estimated by DOI, USDA, and NASA, which together account for about 500 facilities. The estimate is a midpoint of a range of estimates, and includes both administrative and remediation costs. Most of these federal facilities are still being assessed and have not yet progressed to the site remediation stage. The ultimate level and timing of these expenditures will depend upon the availability of resources and technologies. Some agencies may take 50 years or more to complete the cleanup of all their hazardous waste sites. The transfer of public properties to private use may require agencies to reallocate resources to clean up properties designated for transfer. As of December 1996, budget data for FY 1996 and FY 1997 were available for 14 civilian federal agencies. These 14 agencies reported spending a total of $317 million for cleanup activities in FY 1996, and estimated their combined 1997 budgetary needs to be approximately $288 million.

- The cost of state remediation programs is uncertain because of a lack of data and the diverse nature of the various state programs. Based on 1995 annual expenditure data for 37 states, EPA estimates that these states and private parties in these states spent a combined $418 million annually for non-NPL site cleanups under state programs, in 1996 dollars. At this rate, these expenditures will total $12.5 billion through 2025. Estimates for the remaining 13 states are not available. The level of these expenditures also is dependent upon the funds available in state cleanup trust funds or other mechanisms used to pay for cleanup activities at non-NPL sites. As of the end of FY 1995, state fund balances totaled $1.5 billion. These values indicate that states have the capability to continue their current level of expenditures. Based on a survey of state officials published in 1994, about half of the cleanup expenditures for non-NPL and non-RCRA sites between 1980 and 1992 were paid by responsible parties.

Site Characteristics

The selection of remedies at contaminated sites depends largely on the types of media and contaminants present. This section describes the types of contaminants and media that are to be remediated in the various market segments.

The data used to develop these estimates vary widely among the market segments. The Superfund (NPL) data are available from the Records of Decision (RODs) for over 900 sites. The characteristics of these sites are assumed to be representative of all NPL sites, including those needing further remediation. The DOD media and contaminant data are based on information from over 3,000 of about 9,000 sites to be remediated as of September 30, 1994. The RCRA estimates are based on data from fewer than 300 of the estimated 3,000 sites to be remediated. Although the DOE estimates are based on data from all 137 installations, the data do not include information from all 10,500 sites at these installations and other properties.

Media

Groundwater and soil are the most prevalent contaminated media. In addition, large quantities of other contaminated material, such as sediments, landfill waste, and slag, are present at many sites. Exhibit 3 shows the most common contaminated media for each market segment. About 70 percent of NPL, RCRA, DOD, and DOE sites have contaminated soil or groundwater, or both. Contaminated sediment, sludge, and surface water also are present, but at fewer sites. Soil and groundwater also are a primary concern for UST sites.

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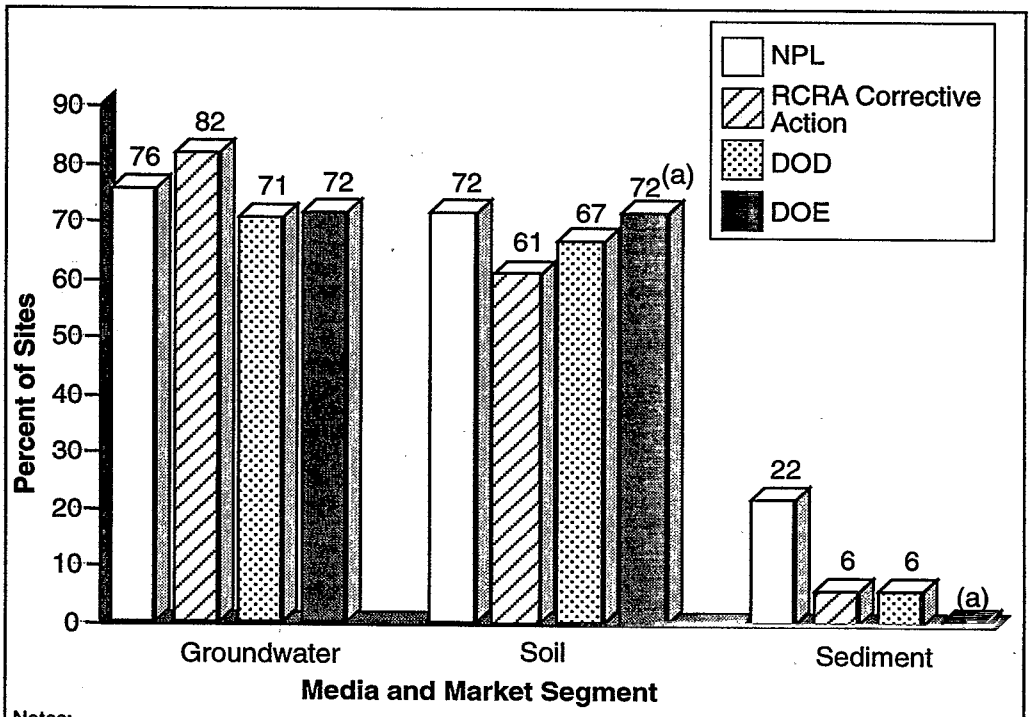
Exhibit 3: Media to be Remediated



Notes:
- (a)DOE soil percentages also include sediment and sludge data.
- 12% of NPL sites contain contaminated sludge; 11% of the surveyed RCRA sites contain contaminated sludge, and 10% contain contaminated surface water; 9% of the DOE sites contain contaminated surface water; and about half of the DOE installations contain contaminated rubble and debris.
- The datasets from which these percentages are estimated are explained in the text.

Contaminants

Many contamination problems and, therefore, technology needs are similar across the major remediation programs. The contaminant groups that are common to most programs are solvents, petroleum products, and metals. Some markets also have more specialized needs arising from wastes that are unique to a particular industrial practice. For example, DOE has a need for technologies to characterize, treat, and dispose of mixed waste; remediate radioactive tank waste; stabilize landfills; and deactivate facilities. DOD is concerned with remediating soils contaminated with explosives and unexploded ordnance.

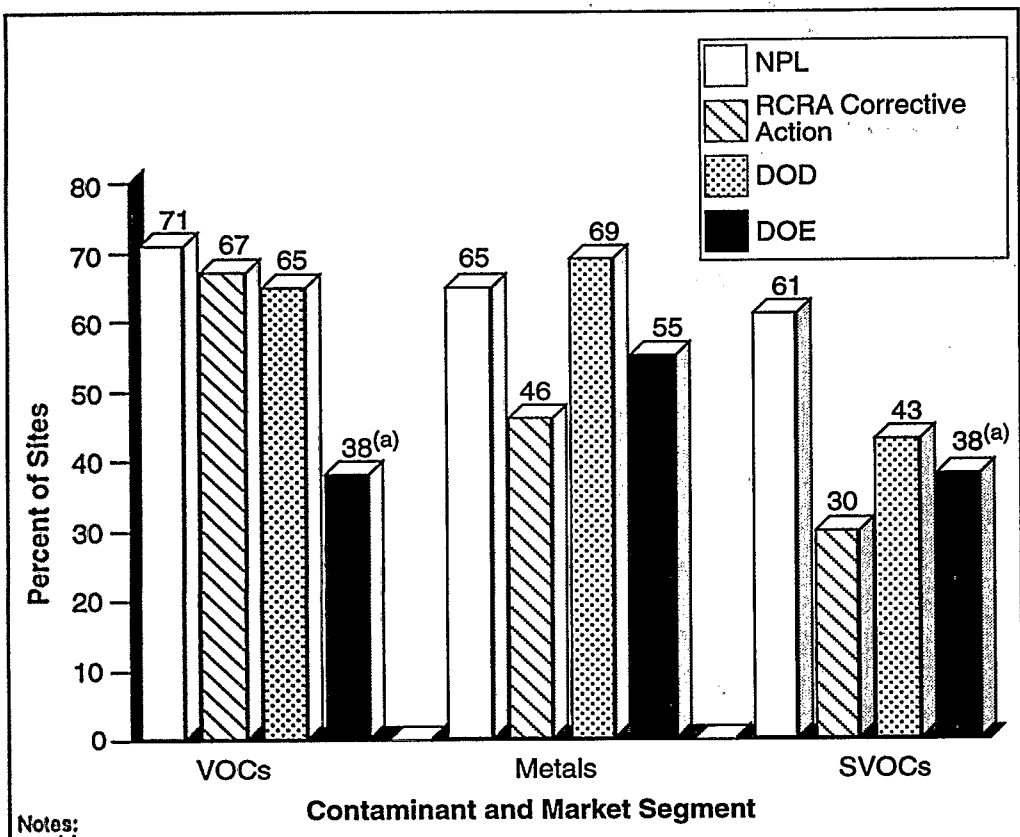
Exhibit 4 shows the frequency of occurrence of the most prevalent contaminant groups. VOCs, the most frequently occurring contaminant type, are present at more than two-thirds of Superfund, RCRA, and DOD sites, and almost half of the DOE sites.

VOCs, the most frequently occurring contaminant type, are present at more than two-thirds of Superfund, RCRA, and DOD sites, and almost half of the DOE installations. VOCs (BTEX) also are the primary contaminants at UST sites.

VOCs, primarily in the form of BTEX (benzene, toluene, ethylbenzene, and xylene) also are the primary contaminants at UST sites. Large numbers of sites to be remediated by other federal agencies and states also are believed to contain VOCs, but only sparse data for these programs are available.

Metals are prevalent in almost all of the major market sectors. Metals, not including radioactive metals, are present at more than two-thirds of the Superfund and DOD sites, and about half of the RCRA and DOE sites. They also are likely to be found in the other market segments. Of the 10 contaminants most frequently found at Superfund and DOD sites, more than half are metals, primarily lead, cadmium, zinc, nickel, chromium, and arsenic.

Exhibit 4: Contaminants to be Remediated



Notes:
- (a)DOE figures for VOCs and SVOCs are combined.
- 22% of the DOD sites contain fuels, 8% explosives, and 1% radioactive contaminants; 90% of the DOE installations contain radioactive elements.
- The datasets from which these percentages are estimated are explained in the text.

Almost all of the market sectors have substantial numbers of sites with metals and VOCs.

The contamination characteristics of each market segment are discussed below.

- For NPL sites VOCs is the most common contaminant group remediated, followed by metals, and SVOCs. Most sites require remediation for more than one of these contaminant groups: 25 percent of the sites contain two contaminant groups and 41 percent contain all three. These contaminants are not necessarily in the same contaminated material. Halogenated VOCs are by far the most common subgroup of organic contaminants, followed by pesticides, polynuclear aromatic hydrocarbons (PAHs) non-halogenated VOCs, polychlorinated biphenyls (PCBs), and phenols. The most common metal cleaned up at NPL sites is lead, followed by chromium, arsenic, and cadmium. NPL data are based on contaminants for which remedies have been selected in the past.

- The most common contaminant groups at RCRA sites are: halogenated VOCs, found at 60 percent of sites; metals, found at 46 percent of sites; and non-halogenated VOCs, found at 32 percent of sites. These estimates are based on two separate studies that used data from fewer than nine percent of all the likely corrective action projects.

- Approximately 96 percent of USTs contain petroleum products and about one percent contain hazardous materials. For USTs containing petroleum products, gasoline accounts for 66 percent and diesel fuel for 21 percent. The most likely constituents of these products that are of concern are BTEX and SVOCs, such as PAHs, creosols, and phenols.

Eight percent of the DOD sites with available data contain explosives and one percent contain radioactive contaminants. In addition, information from some installations indicates that the presence of unexploded ordnance may be significantly greater than these percentages indicate.

- Based on information on 34 percent of the over 9,000 DOD sites that needed remediation as of September 1994, metals are found at 69 percent of the sites, followed by VOCs at 65 percent of the sites, and SVOCs at 43 percent of the sites. Although many similar contaminants also are frequently found at non-defense related sites, some DOD sites contain contaminants that present unique problems for selecting remediation approaches. For example, about eight percent of the over 3,000 DOD sites with available data contain explosives, and about one percent contain radioactive contaminants. The most frequently found specific contaminants in all media are lead, zinc, barium, nickel, cadmium, and copper. The most common organic chemicals are trichloroethylene (TCE) and benzene. In addition, information from some DOD installations indicates that the presence of unexploded ordnance may be significantly larger than the above available information indicates. DOD currently is investigating the potential extent of unexploded ordnance contamination.

- Site assessment and characterization are still in progress at 86 DOE installations and other locations. Although information about the extent of contamination at these installations is incomplete, DOE has made substantial progress in identifying specific contaminants of concern. Radioactive contaminants are found at 90 percent of the installations and include uranium, tritium, thorium, and plutonium. The most

frequently present non-radioactive metals, which are found at 55 percent of the installations, include lead, beryllium, mercury, arsenic, and chromium. Organic chemicals are found at 38 percent of DOE installations and include PCBs, hydrocarbons from fuel and other petroleum products, and TCE. Mixed waste, containing radioactive and hazardous contaminants, also is a problem at many installations. The available data do not indicate if a specific contaminant has been identified at only one site or at more than one site on an installation.

Radioactive contaminants are found at 90 percent of the DOE installations and non-radioactive metals are found at 55 percent.

- Waste at civilian federal agency and state sites is typical of industrial facilities and include organic chemicals, metals, and solvents. However, no national compilation of the specific contaminants at these sites is available.

Technologies

Site characteristics, technology development efforts, and trends in remedial technology use for Superfund sites provide some indication of future technology demands. This section describes the historical use of specific technologies; active technology development programs that have identified and begun to address specific technology gaps; and the outlook for the use of technologies.

In the Superfund program, the selection of treatment has been declining for the past two years, while containment-only remedies have increased. In the UST program, the use of *in situ* technologies has been increasing. Some innovative technologies, primarily soil vapor extraction, thermal desorption, and bioremediation, now are more routinely used.

Technology development programs have become significantly more focussed and, in the next few years, may introduce new or improved methods in the high-demand areas of *in situ* soil and groundwater treatment, biotechnology, and metals treatment.

History and Outlook for Technology Applications

General Trends

The most comprehensive information on technology use at waste sites is available for the Superfund program. Although Superfund sites represent a small percentage of all contaminated sites, experience with technology applications at these sites is likely to influence technology selection in the other market segments.

With the enactment of the 1986 amendments to CERCLA, remedies selected in RODs that address the source of contamination (primarily contaminated soil, sludge, and sediment) shifted away from containment towards treatment to reduce the toxicity, mobility, or volume of a waste. Between FY 1988 and FY 1993, some treatment for part of the site was selected for

almost three-quarters of these source control RODs (source control RODs account for about two-thirds of all RODs).

Although the use of containment-only remedies at Superfund sites has recently increased, treatment remedies are still more common.

In FY 1994 and FY 1995, treatment declined to 59 percent and 53 percent of the sites, respectively (Exhibit 5). Containment-only remedies (capping and landfilling) at these sites increased to 36 percent and 41 percent, respectively. The shifts in the distribution of remedies selected may be explained, in part, by an increase in the number of remedies selected for landfills. The concurrent drop in the selection of solidification/stabilization remedies suggests that, in some cases, containment may be replacing this technology as a remedy for metals in soil.

The selection frequencies for 11 types of source control treatment technologies are illustrated in Exhibit 6. Solidification/stabilization (also called "fixation" and "immobilization") has been the most common technology to treat soil and other wastes. It has been the favored technology to treat metal-containing waste, although its selection has declined in the last two years. Relatively few alternative technologies have been selected for metals. In some cases, solidification/stabilization is selected to treat organic contaminants, primarily SVOCs.

Incineration has been the second most frequently selected of any technology for treating soil, sludge, and sediment in Superfund. The major advantage of incineration is its ability to achieve stringent cleanup standards for highly concentrated mixtures. The selection of on-site incineration has declined to less than four percent of source control technologies selected from 1993 through 1995, primarily because of its cost and a lack of public acceptance. Off-site incineration, the use of which also has dropped, is feasible for only relatively small waste quantities.

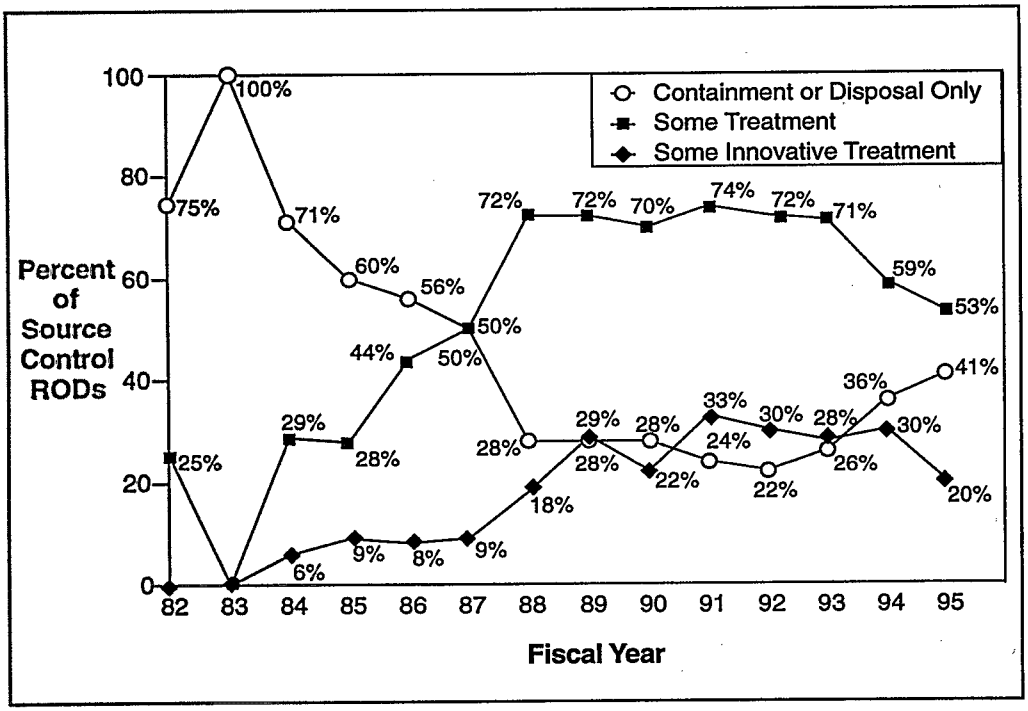
New Technologies

New technologies offer the potential to be more cost-effective than conventional approaches. *In situ* technologies, in particular, are in large demand because they are usually less expensive and more acceptable than above-ground options. For example, state UST program managers report significant increases in the use of *in situ* processes, especially bioremediation, which is effective because of the inherent biodegradability of petroleum hydrocarbons. New technology development programs (Section 1.5.2) include efforts to help meet this demand by emphasizing *in situ* technologies, in particular bioremediation and enhancements to soil vapor extraction (SVE).

SVE has become the preferred technology for both chlorinated and nonchlorinated VOCs in soil.

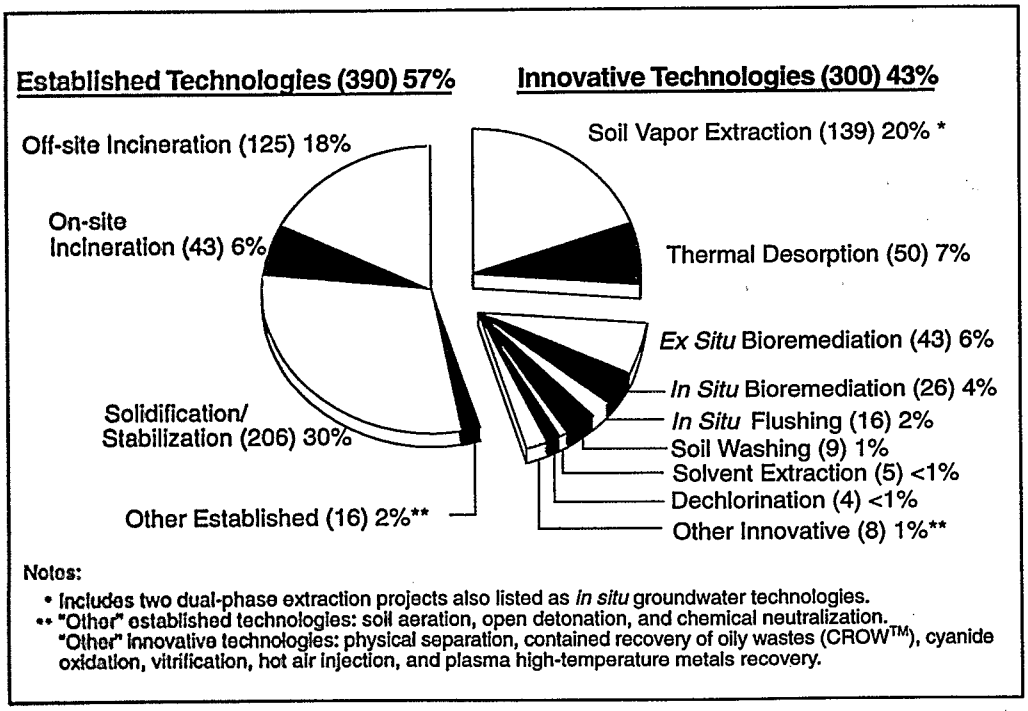
SVE is a flexible *in situ* process that has become much less costly than competing *ex situ* methods. SVE has become the preferred technology for both chlorinated and nonchlorinated VOCs in soil. While the selection of SVE for Superfund sites had recently decreased, its applicability may expand as a result of ongoing efforts to develop enhancements, such as

Exhibit 5: Treatment and Disposal Decisions for Source Control at NPL Sites



Although the use of SVE, bioremediation, and thermal desorption at NPL sites has leveled off, these technologies have potential for the other market segments.

Exhibit 6: Source Control Technologies Selected for NPL Sites Through FY 1995



Notes:

- Includes two dual-phase extraction projects also listed as *in situ* groundwater technologies.
- ** "Other" established technologies: soil aeration, open detonation, and chemical neutralization. "Other" innovative technologies: physical separation, contained recovery of oily wastes (CROW™), cyanide oxidation, vitrification, hot air injection, and plasma high-temperature metals recovery.

methods to increase soil permeability or contaminant volatility. Examples of some enhanced applications include bioventing, directional drilling, and thermal processes. Also, because the other market segments contain VOCs, they may represent a significant market for SVE.

Bioremediation is one of the few alternatives to incineration for actually destroying organic contaminants. The selection of this technology for Superfund sites has remained relatively constant in recent years. Industry and government environmental officials have expressed a strong interest in continuing the development of biotechnology. A large number of laboratory and field tests are under way on the use of bioremediation to degrade commonly occurring chlorinated organics such as TCE and vinyl chloride.

The selection of thermal desorption also has remained relatively constant over the past several years. Applications for thermal desorption include soil contaminated with VOCs (particularly when SVE is not feasible), SVOCs (particularly PCBs and PAHs), and potentially for soils containing both metals and organics. Because other market segments have similar contamination problems, bioremediation and thermal desorption are likely to have applications outside the Superfund program.

Although metals are common at waste sites, treatment alternatives are limited. More effective technologies are needed to treat metals in soil.

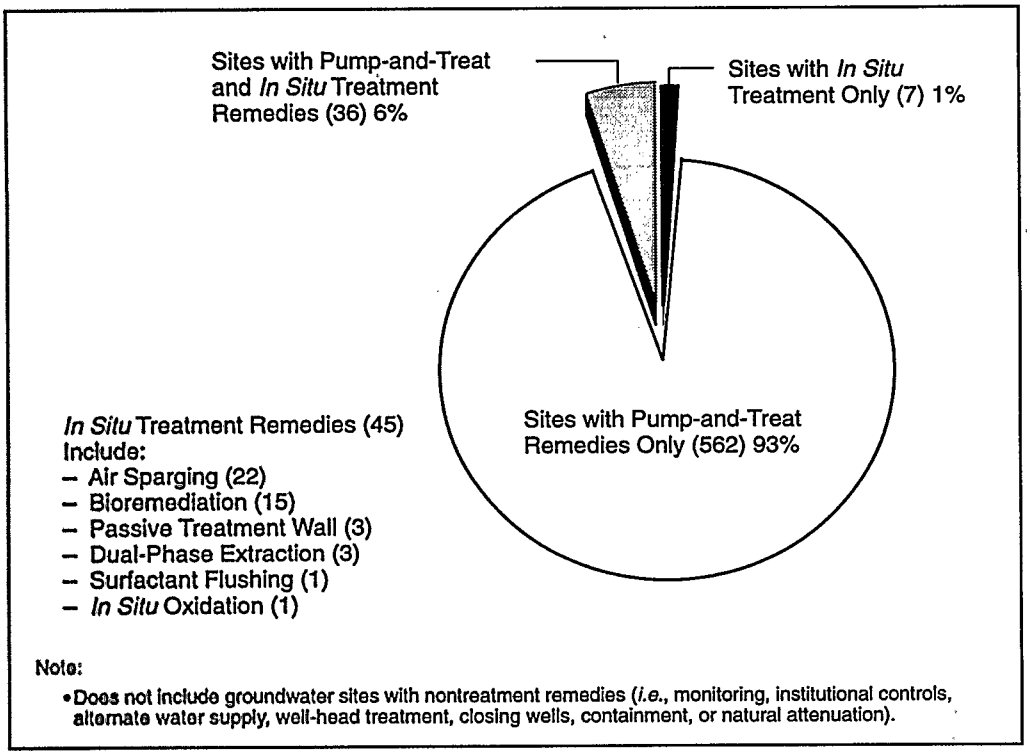
Although metals are common at sites in most of the market segments, alternatives to treat metals are limited. Government and corporate owners of contaminated sites have targeted several technologies to treat metals in soil for further development, including electrokinetics and phytoremediation. Although solidification/stabilization has been the most widely used technology to treat metals, its use in the Superfund program has dropped. The decline in the selection of this technology may signal an opportunity for more cost-effective treatment alternatives.

If more effective in situ *groundwater technologies were available, a larger portion of contaminated groundwater sites could be fully remediated.*

Groundwater is contaminated at more than 70 percent of the sites in most of the market segments. However, not all of these sites will be actively remediated. Available technology cannot always meet the desired cleanup goals for a site, because the methods leave residual aquifer contamination, known as non-aqueous phase liquids (NAPLs). The most frequently used method for groundwater remediation at Superfund sites is conventional pump-and-treat technology, which has been selected for 98 percent of the over 600 NPL sites where groundwater is to be treated (Exhibit 7). The goal of many of these cleanups is to restore the aquifer to beneficial use. Other projects are designed to keep the contamination from spreading. *In situ* treatment technologies, primarily bioremediation and air sparging, have been selected at only six percent of Superfund groundwater treatment sites, most of which also are using pump-and-treat. New management approaches recently receiving more attention include treatment walls and selective application of natural attenuation. If more effective *in situ* groundwater technologies were available, a larger portion of contaminated groundwater sites could be fully remediated.

Comprehensive data on remedy use for UST sites have been compiled from the responses of state officials to a written survey. Although the respondents were asked only to provide estimates, without necessarily

Exhibit 7: Groundwater Treatment Remedies at NPL Sites Through FY 1995



conducting rigorous file searches, the information is extensive, reflecting responses from 49 states. For UST sites undergoing remediation of soil at the time of the survey, the remedial methods used were: landfilling (34 percent of sites), natural attenuation (28 percent), biopiles (16 percent), SVE (9 percent), landfarming (7 percent), thermal desorption (3 percent), incineration (2 percent), bioventing (0.8 percent), and soil washing (0.2 percent). For sites with groundwater contamination, the most commonly used methods were natural attenuation (47 percent), pump-and-treat (29 percent), air sparging (13 percent), *in situ* bioremediation (5 percent), dual-phase extraction (5 percent), and biosparging (2 percent).

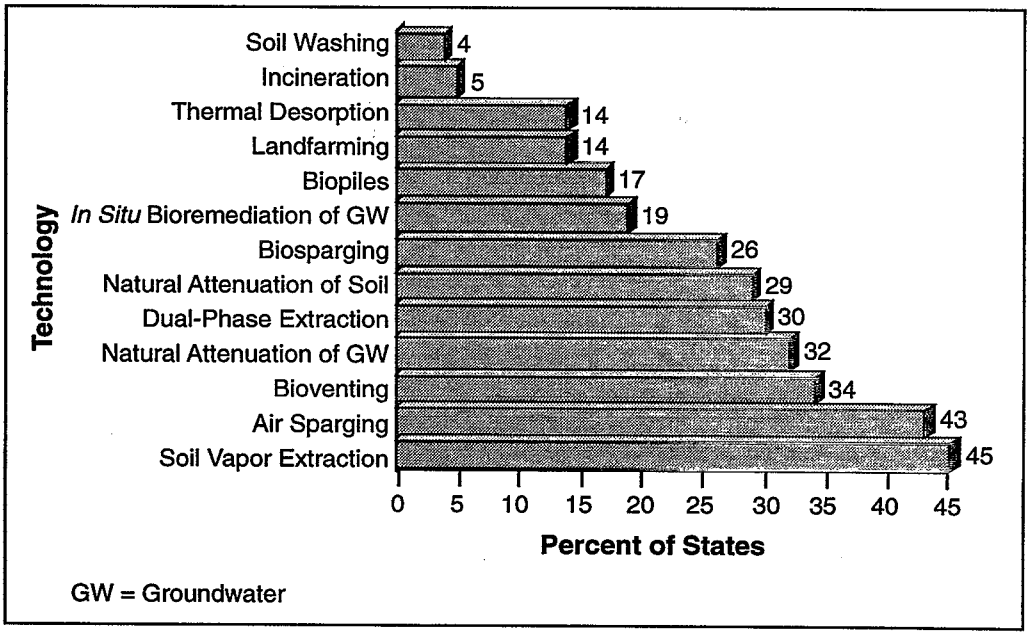
The use of in situ *processes at UST sites has been rapidly increasing. More biological processes are used for UST sites than for the other market segments.*

Although many of these percentages appear low, this market segment includes a substantial number of sites, since over 165,000 UST sites will require cleanup in the future. Moreover, the relative usage levels for many of these technologies had increased substantially over the years prior to the survey. According to the survey respondents, the use of *in situ* processes increased significantly from 1993 to 1995 (Exhibit 8). The UST program technologies include more biological processes due to the inherent biodegradability of petroleum hydrocarbons.

Technology Development Efforts

Future technology use will be influenced by current and planned technology development efforts and the expressed needs of industry and other entities with responsibility for site cleanups. Federal agencies

Exhibit 8: Percent of States With Increased Use of Treatment Technologies at UST Sites: 1993 to 1995



currently are coordinating several technology development and commercialization programs. Of these, two cooperative public-private initiatives are particularly noteworthy because they focus on processes that private "problem holders" view as most promising for the future. The involvement of technology users helps to assure that the processes selected for development reflect actual needs and have a high potential for future application. The technologies identified by these programs and federal agencies provide a useful overview of future trends (Exhibit 9).

Government and private organizations have developed formal programs to cooperatively ensure that technology development efforts are directly related to cleanup needs.

The Remediation Technologies Development Forum (RTDF) is a consortium of partners from industry, government agencies, and academia, who share the common goal of developing more effective, less costly hazardous waste characterization and treatment technologies. RTDF achieves this goal by identifying high priority needs for remediation technology development. For each need, RTDF organizes an Action Team, comprised of organizations who share that interest, to plan and conduct collaborative laboratory and field research and development. Although federal agencies provide in-kind contributions and funding, the formation of teams is driven by the organizations responsible for site cleanups. Five Action Teams have been established to date.

Through the Clean Sites Public-Private Partnerships for technology acceptance, EPA and Clean Sites, Inc., a nonprofit firm, develop partnerships between federal agencies (such as DOD and DOE) and private site owners (responsible parties, owners/operators) for the joint evaluation of full-scale remediation technologies. The purpose of this program is to create a demand among potential users of new technologies by allowing

Exhibit 9: Examples of Technology Needs Identified by Users in Selected Federal Programs

Medium	Clean Sites Public-Private Partnerships	Remediation Technologies Development Forum	Department of Energy
In Situ Management of Soils	• Lasagna™ (electroosmosis, hydrofracturing treatment zones)	• Lasagna™ • Co-metabolic bioventing • Phytoremediation for metals	• Electrokinetics • Vitrification
In Situ Management of Groundwater	• Anaerobic bioremediation • Permeable treatment walls • Air sparging	• Accelerated anaerobic bioremediation • Permeable treatment walls • Intrinsic bioremediation	• Recirculating wells • Microbial filters • Bioremediation • Biosorption of uranium
In Situ Management of Soil and Groundwater	• Rotary steam drilling • Dual-phase extraction	• Not applicable	• Dynamic underground stripping
Ex Situ Management of Soil	• Enhanced bioslurry reactors	• Not applicable	• Innovative soil washing
Ex Situ Management of Groundwater	• Membrane separation	• Not applicable	• Not applicable

the end-users of the technologies to be involved throughout the demonstration process. Typically, Clean Sites, with the assistance of federal agencies, identifies and characterizes a candidate federal facility, solicits industry participation, and brings together the facility and private companies. Based on common problems identified by these partners, the host facility arranges for the procurement of technologies for demonstration. The partners develop evaluation plans and conduct the demonstrations. Currently, there are six evaluation projects in this program.

A recent DOE report enumerated 15 new technologies, scheduled to be available by the year 2000, that may potentially lead to cost savings in cleaning up DOE sites. These technologies are specific examples of the types of technologies that DOE expects to need in the near future, such as bioremediation, electrokinetics, and biosorption of uranium.

Prospective technology users are interested in applying in situ *processes for future cleanups, because they are cheaper, more acceptable to the public, and pose lower risk to workers.*

The technologies selected for development in these three programs demonstrate that prospective users are interested in using *in situ* processes and biotechnology to meet their future needs (Exhibit 9). Various biological methods often are cited, especially for chlorinated solvents. Several technologies rely on SVE as a component, including dual-phase extraction, air sparging, dynamic underground stripping, and rotary steam drilling. Also, several processes entail the creation of treatment zones (permeable barriers, microbial filters, and the Lasagna™ process) and the use of electric fields to mobilize both organics and inorganics.

DOD also has been active in developing and commercializing technologies. DOD's high priority cleanup technology needs include: detection, monitoring and modeling (primarily related to unexploded ordnance

[UXO] and DNAPLS); treatment for soil, sediment, and sludge (primarily related to UXO, white phosphorous contaminated sediments, inorganics, explosives in soil, explosives/organic contaminants in sediments); groundwater treatment (explosives, solvents, organics, alternatives to pump-and-treat, and DNAPLS); and removal of UXO on land and under water.

Cleanup Program Status and Factors Affecting Demand

The demand for remediation services is driven largely by federal and state requirements and public and private expenditures. Changes in these conditions will affect each of the seven market segments in a different way, since each market has its own priorities and operating procedures. Thus, successful planning for technology development and marketing of remediation services should include consideration of the program structure, requirements, and site characteristics of the specific market sectors as well as the shifting requirements and budgets. For example, both government and industry are showing an interest in using risk assessment to determine cleanup priorities, as may be done under the Risk Based Corrective Action initiative in the UST program. Similarly, cleanup program decision-making may become more dependent upon exposure assessments that consider future land use and bioavailability. The most prevalent factors that could alter the scope of the cleanup effort, as well as the technologies to be used in each market, are described below.

Superfund Sites

Superfund is now facing reauthorization, and budgetary and regulatory changes are likely to affect the extent and types of cleanup actions.

The Superfund program is the federal program to clean up releases of hazardous substances at abandoned or uncontrolled hazardous waste sites. Superfund is administered by EPA and the states under the authority of the CERCLA. The procedures for implementing the provisions of CERCLA substantially affect those used by other federal and state cleanup programs. These procedures are spelled out in the National Oil and Hazardous Substances Pollution Contingency Plan, commonly referred to as the National Contingency Plan (NCP). The NCP outlines the steps that EPA and other federal agencies must follow in responding to "releases" of hazardous substances or oil into the environment. Although the terminology may differ from one market segment to another, each follows a process more-or-less similar to this one. Thus, in addition to comprising a defined market segment, activities in the Superfund program substantially influence the implementation of the other market segments.

The Superfund Amendments and Reauthorization Act of 1986 (SARA) made important changes to the Superfund program that are of particular importance to technology vendors. These changes stressed the importance of permanent remedies and support the use of new, unproven treatment technologies. Superfund is facing reauthorization again, and it is likely that budgetary and regulatory changes will occur during the next few years. Some of the Superfund program changes that have been proposed in Congress could significantly impact the markets for remediation

technologies. For example, proposed modifications would require greater consideration of land use in setting cleanup standards, emphasize the treatment and disposal of only the highly contaminated and highly mobile media, limit the addition of new sites to the NPL, and change the liability aspect of CERCLA to reduce the cost and time needed to assign the liability for a cleanup project. Some of these changes are already being implemented, to some extent, under EPA administrative reforms.

In the past four years, the number of Superfund sites that have progressed from study and evaluation to actual cleanup has risen steadily. Thus, a greater portion of the effort is going to the actual cleanup of sites as compared to study and evaluation. Over its 17 year history, the primary responsibility for construction contracting at NPL site cleanups has shifted from EPA to responsible parties. In the past few years, 70 percent of remedial action starts (*i.e.,* actual cleanup activities) have been implemented by responsible parties with EPA or state oversight.

RCRA Corrective Action Sites

The remediation of RCRA "characteristic" or listed waste is addressed under the RCRA corrective action program, which is administered by EPA and authorized states. The current program strategy stresses stabilizing contaminated media to prevent the further spread of contamination before long-term cleanups can be undertaken, and developing priorities for directing resources to the highest priority facilities. High-priority facilities are the main focus of EPA's program to stabilize contaminated media because of their perceived risk to human health and the environment.

The demand for remediation of RCRA corrective action sites is likely to be influenced by a major rulemaking and forthcoming reauthorization.

The demand for remediation of RCRA corrective action sites is likely to be influenced by a new rulemaking called the *Hazardous Waste Identification Rule for Contaminated Media* (HWIR-Media), which was proposed on April 29, 1996. This proposed rule would modify the RCRA Subtitle C management requirements that apply to hazardous remediation wastes generated as a part of government-overseen cleanups (such as RCRA corrective action, Superfund, and cleanup under other state programs). The proposal addressed a number of issues such as: exempting remediation wastes from certain Subtitle C management requirements; modifying land disposal restrictions; streamlining requirements for cleanup permits (including exempting cleanup-only permits from the requirement for facility-wide corrective action); and streamlining state authorization. EPA expects that the final HWIR-Media rule will be an essential complement to the final RCRA Subpart S corrective action regulations.

As part of the President's initiative for reinventing environmental regulations, the Administration has, with input from interested parties, identified potential legislative amendments to provide appropriate relief for high-cost, low-benefit RCRA provisions. The administration believes any reforms to RCRA should proceed separately from CERCLA reauthorization. A key area identified for potential reform is the application of RCRA Subtitle C to remediation wastes.

Underground Storage Tank Sites

Contamination resulting from leaks and spills from underground storage tanks (USTs) are addressed primarily by the tank owners under state UST programs established pursuant to Subtitle I of the 1984 Hazardous and Solid Waste Amendments to RCRA. This law has compelled cleanup activities at many UST sites, providing opportunities for the application of a variety of remedial technologies. It is expected that cleanup activities will increase as a result of the December 1998 deadline for upgrading tanks for corrosion protection.

Because the program is primarily implemented by the states, funding and programmatic considerations at the state level determine the extent and timing of the remediation. All states and territories have passed legislation for UST cleanups, and 45 have state trust funds. Some states have more active enforcement programs than others and some have promulgated UST requirements that are more stringent than the federal standards, such as a requirement for double-lined tanks, more stringent monitoring procedures, or earlier upgrading compliance dates. Although such requirements may increase the magnitude of the remediation work or change its timing, the requirements of specific states were not included in the estimates of market size presented in this report.

Department of Defense Sites

After dropping 16% in FY 1995, the DOD cleanup budget has remained steady, and is expected to continue at its current level. Program activities have been shifting from site investigations to remediation, and from general site restoration to the cleanup of facilities scheduled to close.

The Department of Defense (DOD) is responsible for cleaning up contamination from numerous industrial, commercial, training, and weapons testing activities. DOD installations typically have multiple contaminated sites regulated by either CERCLA, RCRA, state laws, two federal statutes that mandate base realignments and closings, or a combination of these. The rate of realignment and closure of DOD facilities and installations will affect the scheduling of site cleanup. DOD is cleaning up closing military bases so that the properties can be transferred to local communities for economic revitalization. Prior to closing or realigning a base, DOD may be required to clean up the site, although cleanup activity may continue after closure.

DOD annual funding for site cleanup grew from $150 million in FY 1984 to $2.5 billion in FY 1994 and declined to $2.1 billion in FY 1995 and 1996. Although the total budget is expected to remain at this level through FY 1997, the proportion allocated to remedial design and remedial action will increase. The proportion of restoration funds targeted for remedial design and remedial action grew from 48 percent in FY 1994 to 61 percent in FY 1995, 64 percent in FY 1996, and 74 percent in FY 1997.

Other factors that will affect the DOD cleanup efforts include proposed new rules for the remediation of munitions at training ranges and the implementation of a new system for prioritizing sites for cleanup. Under this new system, DOD may assign varying levels of priority to different sites on a given installation. This policy may lead to the acceleration of

some projects at a given installation while causing other projects at the same installation to be postponed.

Department of Energy Sites

DOE is responsible for cleaning up installations and other locations that have been used for nuclear weapons research, development, and production for over five decades. In addition to large, complex government-owned properties, DOE is responsible for cleaning up thousands of private residential and commercial properties that are contaminated because uranium mill tailings were used as fill for construction and landscaping or were carried by the wind to open areas. Environmental problems at DOE sites include unique radiation hazards, large volumes of soil and groundwater, and contaminated structures used to contain nuclear reactors and chemical plants for the extraction of nuclear materials.

Three key factors could affect the DOE market. First, the cleanup approaches used will directly determine both specific technologies to be applied and costs. DOE plans to place greater emphasis on containment than on treatment and other active remediation strategies. Second, the level of the DOE budget, which has been debated in Congress, could significantly alter the scheduling of site restoration and technology development projects. Third, the nature and magnitude of the contamination at many DOE sites is still only partially known; only about 46 percent of the more than 10,500 sites have been fully characterized. As sites are further investigated and new technologies to address the contamination problems become available, it may be necessary to alter budgets and the demand estimates for specific technologies.

The DOE cleanup market estimates relied on several critical assumptions, which makes them particularly sensitive to budget fluctuations, cleanup standards, and further site investigations.

Civilian Federal Agency Sites

"Civilian" federal agencies (CFAs) include all federal agencies except DOE and DOD. These agencies are responsible for the cleanup of contaminated waste at currently or formerly owned facilities. Under SARA, the federal government also may be liable for cleaning up contaminated waste at facilities acquired through foreclosure or other means and facilities purchased with federal loans. To meet these requirements, civilian federal agencies have established programs to assess potentially contaminated sites, and, if necessary, clean them up. Because detailed data on CFA site characteristics are limited, more site investigation is needed to fully identify cleanup needs. The programs are considerably smaller than those of DOD and DOE. The FY 1997 budget for 14 agencies combined is $288 million, about 14% of DOD's environmental restoration budget.

In managing their environmental restoration programs, civilian federal agencies are subject to the same technical and political issues as are DOD and DOE. Future funding for site restoration at most civilian federal agencies is uncertain. To address this uncertainty, program managers have recognized the need to prioritize cleanup activities and to find better, faster, and less expensive cleanup approaches.

State and Private Party Sites

The financial and legal commitment to site restoration varies from state to state. Many states have programs to encourage voluntary cleanups and develop brownfield properties.

All sites not owned by federal agencies that require cleanup, but cannot be addressed under the federal Superfund, RCRA corrective action, or UST programs, are addressed by state cleanup programs. The cleanup of these sites must be financed by the states or private parties. To manage the cleanup of contaminated sites, many states have created their own programs patterned after the federal Superfund program. These programs generally include enforcement authority and state funds to finance the remediation of abandoned waste sites. Although enforcement activities vary from one state to another, most states have the legal authority to initiate or compel the cleanup of sites, recover costs from responsible parties, and seek criminal or civil penalties. The extent and pace of a state cleanup program is ultimately determined by its financial and legal commitment to environmental restoration.

Voluntary cleanups and "brownfield" sites represent another potential market for hazardous waste remediation services. Although the full extent of this market is unknown, 34 states have developed formal voluntary programs which are designed to promote the timely evaluation and remediation of waste sites with a minimum of state oversight and expenditure and to allow these properties to return to economically productive use. "Brownfields" are abandoned, idle, or under-used industrial and commercial facilities where real or perceived environmental contamination may be hampering expansion or redevelopment. The investigation and cleanup of these sites is a high priority among both environmental protection and economic development authorities at both the state and federal levels.

Using the Full Document

Chapter 2 of the full document describes the recent trends in the use of remedial technologies at Superfund sites. Because many contamination problems are similar across the seven market segments, the Superfund technology information is useful to help understand potential technology trends in the other markets. The remaining seven chapters address each of the market segments.

For each market segment, five areas are discussed: (1) the structure, operation, and regulatory requirements of the program; (2) the economic and political factors that may change the size or characteristics of the market segment; (3) the quantitative measures of the market in terms of the number of sites, occurrence of contaminants, and extent of remediation work needed; (4) remediation cost estimates; and (5) procurement and technology issues. Citations are referenced at the end of each chapter.

Appendices A through H contain supporting data, sources for additional information on the remediation market and technologies, and definitions of terms used in the report.

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