Brownfields Road Map to Understanding Options for Site Investigation and Cleanup

Course No: C06-019
Credit: 6 PDH

Gilbert Gedeon, P.E.

Continuing Education and Development, Inc.

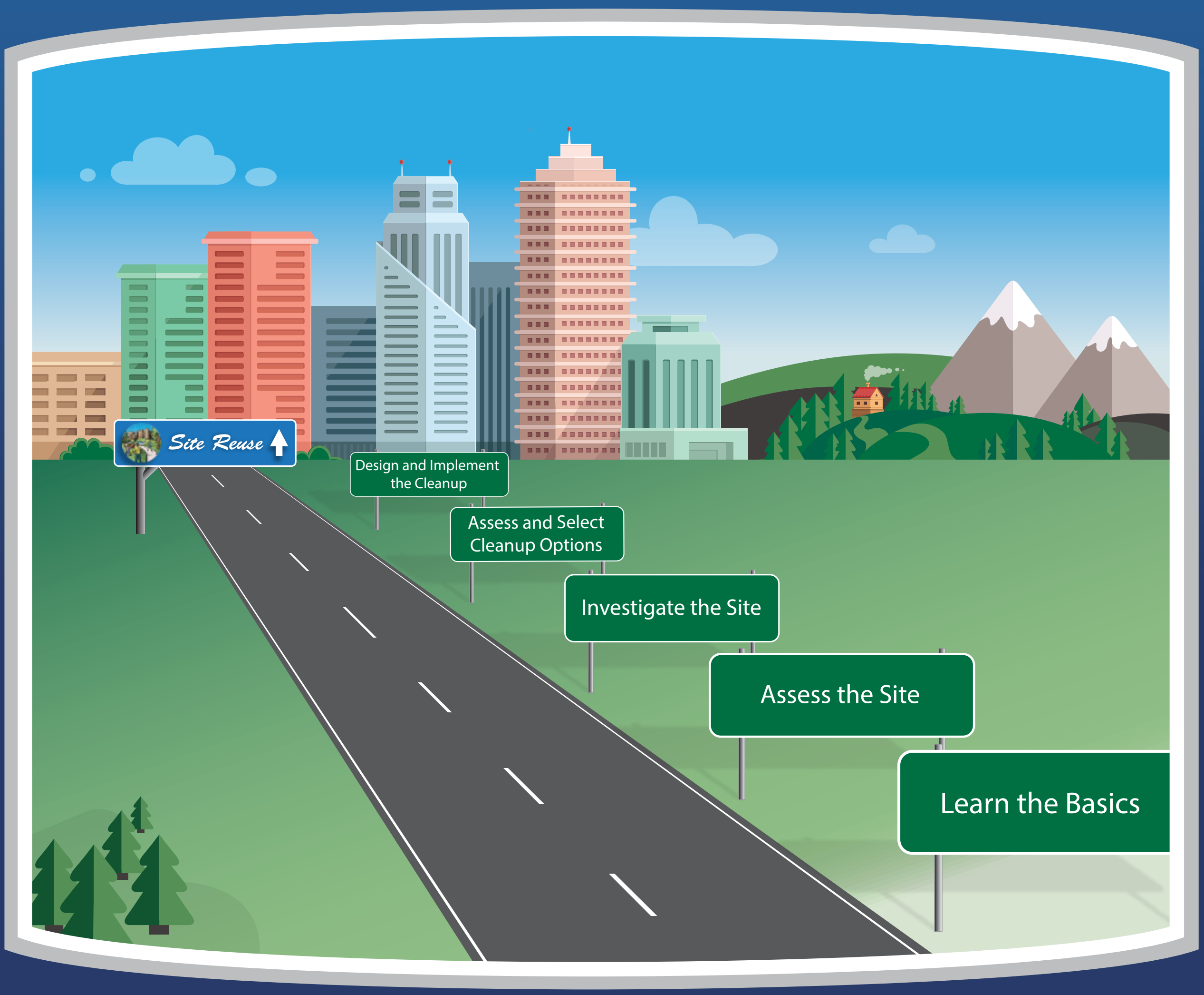
P: (877) 322-5800
info@cedengineering.com

Office of Land and Emergency Management
EPA 542-R-17-003

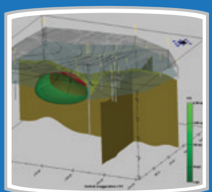
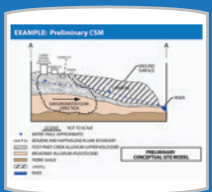
United States
Environmental Protection
Agency

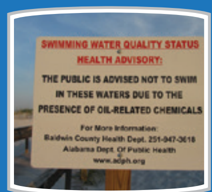
Brownfields Road Map to Understanding Options for Site Investigation and Cleanup

Sixth Edition



www.epa.gov/brownfields/brownfields-roadmap

[This page is intentonally left blank]

Table of Contents

Introduction

Helping stakeholders understand options for site investigation and cleanup

The Brownfields Road Map

The Sixth Edition features these updates:

- Additional details to assist stakeholders with planning their Brownfields projects
- General assistance for developing each phase of site investigation and cleanup
- "Spotlights" on 10 current issues and best management practices (BMPs)
- New and updated ASTM standards
- Discussion of greener cleanup and resilient revitalization best practices

The *Brownfields Road Map to Understanding Options for Site Investigation and Cleanup, Sixth Edition*, provides a general outline of the steps in the investigation and cleanup of Brownfields sites and introduces Brownfields stakeholders to the range of technologies and resources available to them. The Road Map provides valuable information for stakeholders typically involved in or affected by redevelopment of Brownfields sites, whether through public projects, private development or public-private partnerships.

The first edition of the Road Map, published in 1997, provided a broad overview of the EPA Brownfields Program and an outline of the steps involved in the cleanup of a Brownfields site. Designed primarily for stakeholders who were unfamiliar with the elements of cleaning up a Brownfields site, the Road Map built awareness of the advantages offered by innovative technologies. As the EPA Brownfields Program matured, the second (1999), third (2001), and fourth (2005) editions were published to update information and resources associated with the program, innovative technologies, and emerging best practices. The fifth edition, published in 2012, streamlined the publication to make it more accessible to users, providing additional resources covering new technology applications and methods.

This edition builds off the streamlined approach of the fifth edition, providing updated content and guidance on the Brownfields remediation process. New features include an updated list of "Spotlights," highlighting and describing key issues. This edition provides updated information on Brownfields funding and best management practices (BMPs), with guidance on how to incorporate greener cleanups and new standards into the cleanup process.

This edition of the Road Map will help:

- ***New and less experienced stakeholders.*** The Road Map will help these users learn about the technical aspects of Brownfields by introducing general concepts and methods for site investigation and cleanup.

- ***Decision-makers who are familiar with the EPA Brownfields Program but are also interested in obtaining more detailed information.*** The Road Map provides these users with up-to-date information about the applicability of technologies and access to the latest resources that can assist them in making technology decisions. In addition, it highlights BMPs that have emerged in recent years.
- ***Community members*.** The Road Map helps to encourage community members to participate in the decision making process by providing information about the general site cleanup process and tools and alternatives to site cleanup, as well as guidelines and mechanisms to promote community involvement.
- ***Tribal leaders.*** The Road Map offers information on technical and financial assistance specific to tribes for implementing cleanup and restoration activities on tribal lands, as well as successful remediation examples highlighting the potential community restoration opportunities associated with Section 128(a) Response Program funding.
- ***Stakeholders who hire or oversee site cleanup professionals*.** The Road Map includes information to help stakeholders coordinate with many different cleanup practitioners, such as environmental professionals, cleanup service providers, technology vendors or staff of analytical laboratories. The Road Map provides these stakeholders with a detailed understanding of each phase in a typical Brownfields site cleanup and presents information about the roles that environmental practitioners play in the process.
- ***Regulators*.** The Road Map will increase the understanding by regulatory personnel of site characterization and cleanup technologies and approaches. The Road Map also serves as a resource that regulators can use to provide site owners, service providers and other stakeholders with useful information about the EPA Brownfields Program. The Road Map also provides links and pointers to additional information on specific technologies, approaches, and issues.
- ***Other potential Brownfields stakeholders*.** The Road Map helps other stakeholders, such as financial institutions and insurance agencies, by providing information for their use in assessing and minimizing financial risks associated with Brownfields redevelopment.

Disclaimer

The Road Map draws on the EPA's experiences with Brownfields sites, as well as Superfund sites, corrective action sites under the Resource Conservation and Recovery Act (RCRA), and underground storage tank (UST) sites to provide technical information useful to Brownfield stakeholders. Specific conditions—such as the nature and extent of contamination, the proposed reuses of the property, the financial resources available, and the level of support from neighboring communities—vary from site to site. Readers of the Road Map are encouraged to explore opportunities to use the BMPs described in the following pages in accordance with applicable regulatory program requirements. The use of BMPs and site characterization and cleanup technologies may require site specific decisions to be made with input from state, tribal, and/or local regulators and other oversight bodies.

This document provides general information and guidance regarding facilitating reuse of properties. The information in this document is pertinent to sites that meet the definition of a Brownfield site and focuses on providing information to Brownfields stakeholders. Users of this document should determine whether their site meets the definition of a Brownfield site before using this document (the term "brownfield site" means real property, the expansion, redevelopment or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant or contaminant). Sites that fall under other regulatory programs such as RCRA corrective action sites or Superfund sites are subject to the requirements of those programs. While some of the information in this document may be helpful to them, they should rely primarily on information sources focused on those types of sites.

This document does not address all information, factors or considerations that may be relevant. This document is not legally binding. The word "should" and other similar terms used in this document are intended as general recommendations or suggestions that might be generally applicable or appropriate and should not be taken as providing legal, technical, financial or other advice regarding a specific situation or set of circumstances. This document may be revised at any time without public notice. Any references to private entities, products or services are strictly for informational purposes and do not constitute an endorsement of that entity, product or service.

This document describes and summarizes statutory provisions, regulatory requirements and policies. The document is not a substitute for these provisions, regulations or policies, nor is it a regulation or EPA guidance document itself. In the event of a conflict between the discussion in this document and any statute, regulation or policy, this document would not be controlling and cannot be relied on to contradict or argue against any EPA position taken administratively or in court. It does not impose legally binding requirements on the EPA or the regulated community and might not apply to a particular situation based on the specific circumstances. This document does not modify or supersede any existing EPA guidance document or affect the Agency's enforcement discretion in any way.

About the EPA Brownfields Program

Brownfields sites are defined as "real property, the expansion, redevelopment or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant or contaminant" (Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended by the Small Business Liability Relief and Brownfields Revitalization Act of 2002, §101(39)). The cleanup of Brownfields sites improves and protects the environment and may result in many benefits for the local community.

The EPA established its Brownfields Economic Revitalization Initiative in 1995 to empower states, communities and other stakeholders in economic revitalization to work together to accomplish the redevelopment of Brownfields sites. The enactment of the Small Business Liability Relief and Brownfields Revitalization Act in 2002 expanded EPA assistance to provide greater support for Brownfields cleanup and reuse. Many states and local jurisdictions also help communities adapt environmental cleanup programs to the special needs of Brownfields sites.

Summary of Brownfields Program Accomplishments as of May 2017

Thousands of properties have been assessed and cleaned up with the support of grants and funding from the EPA Brownfields Program.

Measure	Cumulative Results
Properties Assessed	26,722
Cleanups Completed	117,000
Direct and Indirect Jobs Created	124,760
Acres Made Ready for Reuse	67,419

Source: www.epa.gov/brownfields/brownfields-program-accomplishments-and-benefits

Revitalizing Brownfields sites has the potential to create benefits throughout the community, including community involvement in the project, job creation, and an increase in residential property values once a nearby Brownfields site is assessed or cleaned up.

How to Submit Comments

The EPA invites comments from members of the Brownfields community to help ensure that any future versions of the Road Map meet their needs. Please submit comments to:

Carlos Pachon
U.S. Environmental Protection Agency
Office of Superfund Remediation and Technology Innovation
pachon.carlos@epa.gov
(703) 603-9904

How to Obtain Additional Copies

A printed or hard copy version of this document can be obtained from the following source:

National Service Center for Environmental Publications
U.S. Environmental Protection Agency
P.O. Box 42419
Cincinnati, OH 45242-0419
Phone: (800) 490-9198
Fax: (301) 604-3408
Email: nscep@lmsolas.com

When you order the Road Map, please refer to document number 542-R-17-003.

Small Business Liability Relief and Brownfields Revitalization Act

Since its inception in 1995, EPA's Brownfields Program has grown into a proven, results-oriented program that has changed the way contaminated property is perceived, addressed and managed. EPA's Brownfields Program is designed to empower states, communities and other stakeholders in economic redevelopment to work together in a timely manner to prevent, assess, safely clean up and sustainably reuse brownfields.

In January 2002, the Small Business Liability Relief and Brownfields Revitalization Act ("The Brownfields Law," Public Law 107-118; H.R. 2869) was signed. The Brownfields Law amended the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) by providing funds to assess and clean up Brownfields, clarified CERCLA liability protections and provided funds to enhance state and tribal response programs. Other related laws and regulations impact Brownfields cleanup and reuse through financial incentives and regulatory requirements.

Key changes to the EPA Brownfields program as a result of the Brownfields Law included:

Improvements to EPA's existing Brownfields grants and technical assistance program by:

- Increasing available grant funding to approximately $100 million annually in recent years
- Providing grants for assessments, revolving loan funds, direct cleanups, area-wide planning and environmental workforce development and job training
- Expanding the entities, properties and activities eligible for Brownfields grants, including sites such as mine-scarred lands
- Expanding applicability to sites with petroleum contamination such as abandoned gasoline stations
- Providing authority for Brownfields training, research and technical assistance
- Allowing local government entities up to 10 percent of the grant funds to be used to monitor the health of exposed populations and enforce any institutional controls

Creation of a strong, balanced relationship between the federal government and state and tribal programs that:

- Authorized up to $50 million per year for building and enhancing state and tribal response programs and expanded the activities eligible for funding
- Provided protection from Superfund liability at sites cleaned up under a state or tribal program
- Preserved the federal safety net by detailing the circumstances in which the EPA can revisit a cleanup
- Clarified the state role in adding sites to the Superfund National Priorities List (NPL)

Additional information on the Brownfields Law is available at www.epa.gov/brownfields/brownfields-laws-and-regulations.

The Sixth Edition of the Road Map presents the general phases involved in the investigation and cleanup of a Brownfields site, introduces the reader to a range of considerations and activities and provides links to online technical resources and tools.

Overview of the Road Map

The Road Map follows the process illustrated in the Brownfields Road Map graphic (see page 8). The first section, Introduction, discusses important factors that set the stage for the investigation and cleanup of Brownfields sites. Sections 2 (Follow the Road Map) and 3 (Learn the Basics) introduce concepts, strategies and methods that can be applied to efficiently and effectively prepare sites for reuse. The remaining sections correspond to the general phases of site characterization and cleanup, from site assessment through implementation of cleanup remedies. The Road Map identifies examples of regulatory considerations to take into account and discusses technologies within the overall framework of site characterization and cleanup.

Spotlights – The Road Map "spotlights" focus the reader's attention on key issues, processes and initiatives. They provide a quick look at topics relevant to Brownfields projects and identify how readers can obtain additional information.

Appendices – Provided at the end of the Road Map document:

Appendix A, CSM and General Cleanup Steps: A Crosswalk of Regulatory Program Stages and Life Cycle Phases, is a crosswalk of specific terms used in different cleanup programs to identify cleanup stages. It puts these terms into the context of the Road Map.

Appendix B, Acronyms, defines acronyms used in discussing and describing Brownfields cleanup efforts.

Appendix C, References and Additional Information, provides a list of references used to develop the document and additional resources.

Understanding the typical progression of the site investigation and cleanup process ensures that the proper groundwork is laid for future phases.

Site investigation and cleanup typically do not occur in the linear sequence outlined in the Road Map. At many sites, several activities may be undertaken concurrently, while others recur throughout the process. Similarly, many technologies that are used to characterize sites during the investigation phase may also be used during the cleanup phase to monitor performance and help reduce uncertainties related to site conditions.

Appendix D, Guide to Contaminants and Technologies, is a guide to contaminants commonly found at types of Brownfields sites and the types of technologies that may be appropriate for their analysis and treatment.

Brownfields Road Map

The Brownfields Road Map illustrates the general steps involved in the investigation and cleanup of a Brownfields site.

Actual steps may vary depending on site conditions and applicable state and federal regulations. Stakeholders should consult with appropriate regulatory agencies throughout the process and enlist qualified technical and legal services.

Learn the Basics

Before you begin down the path outlined in the Road Map, it is important to get prepared. Preparation typically consists of the following activities:

- Setting reuse goals and planning
- Understanding regulations, regulatory guidelines and liability concerns
- Engaging the community
- Identifying funding
- Seeking professional support

Begin Here

Spotlights

The Road Map "spotlights" highlight key issues, processes and initiatives. Each spotlight provides a summary of topics relevant to Brownfields projects and identifies related resources. The following spotlights are included in the Road Map:

Learn the Basics

1. Innovations in Contracting
2. Supporting Tribal Revitalization

Assess the Site

3. Project Life Cycle Conceptual Site Model

Investigate the Site

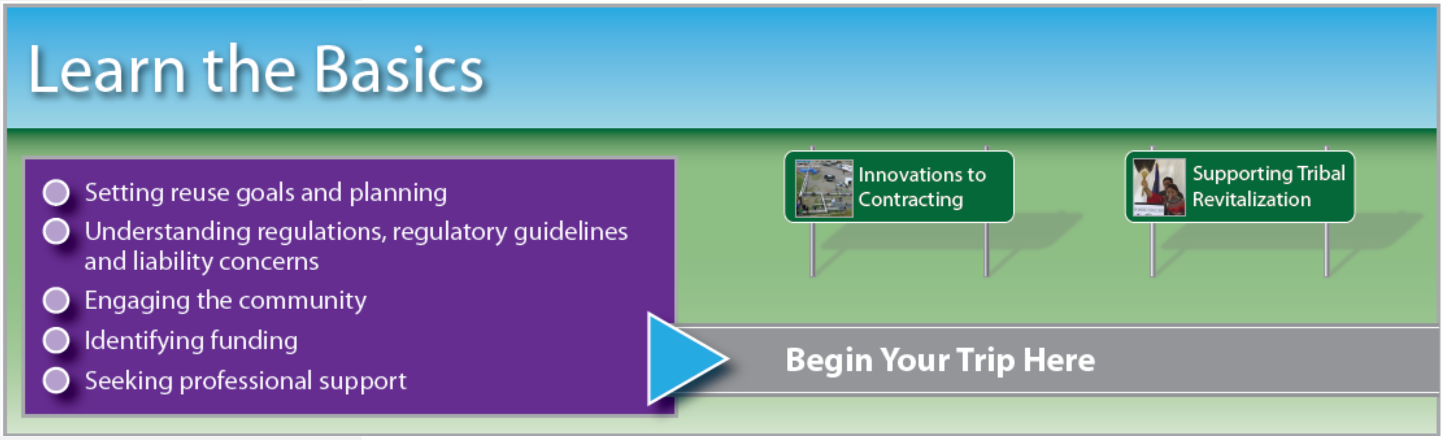
4. Vapor Intrusion
5. Mining Site Redevelopment

Assess and Select Cleanup Options

6. In Situ Technology
7. Greener Cleanup Best Practices
8. Understanding the Role of Institutional Controls

Design and Implement the Cleanup

9. Optimization Best Practices for Challenging Cleanups
10. Resilient Revitalization



Begin here to learn about factors and considerations that affect cleanup at a Brownfields site. These “basics” are integral to the cleanup process and the overall success of the Brownfields project.

General concepts and terms related to the investigation and cleanup of Brownfields sites are introduced here and reinforced throughout the publication.

Brownfields Stakeholders

A stakeholder is typically considered to be an individual who can influence decisions or is impacted by decisions regarding sites. Stakeholders for Brownfields projects may include:

- Federal, state, tribal and local agencies
- Local elected officials
- Local and regional community development agencies
- Developers
- Community members
- Tribes
- Property owners
- Academia
- Potentially responsible parties (PRPs)
- Private business and industry
- Non-profit organizations

Brownfields projects may be initiated for a number of reasons. A landowner may want to sell a property to a prospective purchaser for development. A municipality may want to clean up a parcel or area that has become a public hazard or eyesore, create space for business development or build a park. A local comprehensive plan may call for infill development of a certain type in a Brownfields area. In these cases, the Brownfields process will be tailored to the specific end use envisioned for the property re-purposing.

Preparing a Brownfields site for reuse involves more than the investigation and cleanup of a property. The interests of many stakeholders must be integrated into the overall redevelopment process. Cleanup strategies vary from site to site, depending on factors such as intended end use, available funding, liability considerations, regulatory requirements, the type and extent of contamination present and the technologies available for cleanup. At some sites, cleanup will be completed before the properties are transferred to new owners. At other sites, cleanup may take place simultaneously with construction and redevelopment.

Regardless of when and how cleanups are accomplished, a key challenge to Brownfields projects is to clean up sites in accordance with reuse goals and appropriate laws and regulations, including changes which might occur during the cleanup process. It is essential that stakeholders become familiar with factors that play a significant role in the success of a Brownfields project, such as understanding applicable regulations, engaging members of the community, identifying funding and obtaining professional support.

The Road Map outlines a general cleanup process and the names of the steps in this process are specific to the cleanup of Brownfields sites. The overall process, however, applies to other cleanup programs as well. Refer to Appendix A (CSM and General Cleanup Steps: A Crosswalk of Regulatory Program Stages and CSM Life Cycle Phases) at the end of this document for more information on other cleanup program steps and terminology.

State Underground Storage Tank/Leaking Underground Storage Tank (UST-LUST) programs have tailored tools to meet site-specific investigation and cleanup needs. For more information, visit the applicable state UST/LUST implementing agency and www.epa.gov/ust/state-underground-storage-tank-ust-programs.

Setting Reuse Goals and Planning

From the outset, it is important to consider potential reuse goals. A reuse plan based on those goals will govern most Brownfields projects, from identifying site investigation and cleanup standards that will prepare the site for the reuse plan, to obtaining competitive financing potentially critical to the ultimate affordability of the project. Keep in mind, however, that new information about contamination or cleanup needs may require that reuse plans be altered. Be prepared to develop a flexible project plan that will evolve as information is collected, community input is received and decisions are made about the cleanup approach.

Establishing reuse goals for a Brownfields project also helps the project team define the specific decisions to be made throughout the project. This is fundamental to selecting appropriate technologies for site investigation and cleanup which enable those responsible for the Brownfields project to collect the data necessary to support those decisions and accomplish the established goals.

The most efficient way to use resources is to identify a redevelopment goal at the beginning of the project. If reuse goals are not known from the outset, Brownfield funds can best be harnessed by establishing a clear redevelopment objective. The stakeholders should at a minimum make every attempt to identify the general type of desired development, whether open space/recreational, industrial, commercial, residential or mixed-use. Without that information, the most conservative assumptions might be applied at every stage of the Brownfields project. While this can provide greater flexibility later in the redevelopment process, it can also significantly increase the time and expense of the project.

Understand Previous and Current Planning Activities that Involve and Affect the Site

Stakeholders should take into account how the Brownfield site fits within the broader planning efforts for the community.

- Read the community's master plan. What are its broad themes (make the community more sustainable or resilient, increase economic growth, increase open space)?
- Determine how the Brownfield site can contribute to one or more of these themes.
- Look at the zoning for the site. What uses are permitted? Would that zoning need to be changed?
- Read the redevelopment plans for the area. How can redevelopment of the site contribute to them?
- Are there any market studies for the area indicating the types of uses that the market would bear?
- Have there been other plans that involved this site in the past? What happened? What lessons can be learned?

With this information, stakeholders can create a planning framework for the site.

State and Tribal Response Programs

State and Tribal response programs—to provide liability clarity or support cleanup at specific sites—continue to be at the forefront of Brownfields cleanup and redevelopment.

State and Tribal Response Program Highlights describe recent progress the states and tribes are making to address contaminated land in their communities.

Further information is available in Spotlight 2 and online at www.epa.gov/brownfields/state-and-tribal-brownfield-response-programs

Understanding Regulations, Regulatory Guidelines and Liability Concerns

The redevelopment of Brownfields sites may be subject to various federal, state, tribal and local laws, regulations, policies and guidelines with respect to the characterization and cleanup of the site. The standard practices of other government, nongovernment and private institutions may also govern these sites.

Example of Regulatory Requirement

If the proposed end use for a Brownfields site calls for construction of a light industrial facility, it may be appropriate, depending on state and local regulatory requirements, to compare the relevant cleanup standards for industrial as well as commercial or residential reuse standards. If the more stringent standard required for commercial or residential reuse is used, additional cleanup and costs may be required initially, but doing so provides greater flexibility and avoids future delays if the proposed reuse is likely to change. The required standards need to be considered throughout the project.

The applicable laws, regulations, policies and guidelines will vary by site, depending on the regulatory authorities that have oversight authority for cleanup. Therefore, it is important to research this information at the outset and to work closely with the regulatory authorities throughout the cleanup process. For example, state, tribal or local regulatory authorities usually oversee the cleanup of Brownfields sites. These agencies should be consulted to determine what, if any, site-specific requirements, reviews, approvals or permits are applicable.

At the EPA, the Office of Site Remediation Enforcement (OSRE) supports cleanup and revitalization by issuing enforcement discretion guidance documents, model enforcement documents, responses to frequently asked questions, fact sheets and other documents. OSRE works with the EPA regional offices to provide guidance on relevant enforcement tools to potential developers and owners of contaminated land. These documents, along with current Superfund enforcement and Brownfields policy and guidance documents, are available on the EPA's website at www.epa.gov/enforcement/brownfields-and-land-revitalization-cleanup-enforcement. The EPA also can be a valuable resource for Brownfields stakeholders by providing regulatory and policy support to facilitate the selection of technologies.

Many of the standard practices are designed to help Brownfields redevelopment projects obtain financing from public programs and private banks and institutions. Guidance and standards are issued by government and nongovernment organizations, such as ASTM International (formerly the American Society for Testing and Materials), the Federal Deposit Insurance Corporation (FDIC), state, tribal and local economic development authorities and private lenders.

Subsequent sections of this Road Map identify regulatory considerations at relevant phases of investigation and cleanup. Stakeholders are encouraged to regularly consult with appropriate regulatory agencies to ensure that requirements are properly addressed throughout the project.

Engaging the Community

Encouraging active participation by members of the community who are most likely to be affected by site cleanup and reuse plans contributes to the success of the project. Engage the community to raise awareness, identify community concerns and build support for cleanup efforts that will lead to redevelopment and revitalization of their community. To maximize chances for success, plan early for how the community stakeholders will be identified and encouraged to participate for the duration of the Brownfields project, from the investigation phases through cleanup.

It is important that Brownfields decision-makers encourage acceptance of reuse plans and cleanup alternatives by involving members of the community through multiple outreach methods such as public meetings, newsletters, publications, websites and social networks. For an individual site, consider how the people living in or near the site might be affected by cleanup activities and the intended reuse of the property; plan early and appropriately for how cleanup decisions and their potential impact will be shared with the community. For example, the community should be informed about how the use of a proposed technology might affect redevelopment plans or the adjacent neighborhood.

Key Resource for Community Engagement

EPA's Brownfields Program is designed to promote the active participation of communities in each phase of the cleanup process so that revitalized land offers the greatest local benefit.

The *Brownfields Stakeholder Forum Kit* is a guide to assist communities in planning effective stakeholder forums by providing tools and tips for engaging stakeholders and establishing partnerships to address revitalization challenges. The kit is available at www.epa.gov/brownfields/brownfields-stakeholder-forum-kit.

Key Resource for Regulatory and Liability Concerns

The Revitalization Handbook, updated and reissued in 2014 by EPA Office of Site Remediation Enforcement (OSRE) is designed for stakeholders involved in the assessment, cleanup and revitalization of sites. The handbook summarizes federal statutory provisions and EPA policy and guidance documents useful for managing liability risks associated with cleaning up sites, and describes tools that stakeholders can use to address liability concerns. The handbook, including recent updates, is available at www.epa.gov/enforcement/revitalization-handbook.

Brownfields Area-Wide Planning Program

The Brownfields area-wide planning program supports community involvement in locally based efforts to plan for the assessment, cleanup and reuse of Brownfields sites within a defined area. Through grants and technical assistance, the program promotes land revitalization affected by a large Brownfields site or multiple Brownfields (for example, revitalization of a neighborhood, block or corridor) and promotes community engagement in the planning for Brownfields revitalization efforts. Details about the program, including project fact sheets and information about applying for funding, are available at www.epa.gov/brownfields/types-brownfields-grant-funding.

Technical Assistance for Communities

The EPA's Technical Assistance to Brownfields (TAB) Communities program is a free resource providing technical assistance to communities and other stakeholders dealing with challenges of Brownfields cleanups. Organized to provide geographically based assistance, the TAB program increases understanding of technical issues associated with Brownfields sites by providing webinars, workshops, one-on-one assistance, newsletters and other tools. The program offers assistance in a wide range of technical areas, including navigating the regulatory process, community involvement, health impacts, science and technology, finance and funding and more.

Details, including how to request technical assistance, are provided online at www.epa.gov/brownfields/brownfields-technical-assistance-and-research#TAB.

The EPA assists Brownfields communities by directing its members to appropriate resources and providing opportunities to network and participate in sharing information. A number of websites, databases, newsletters and reports provide opportunities for Brownfields stakeholders to network with other stakeholders to identify information about cleanup and technology options. Details about the EPA's community engagement efforts by the Office of Land and Emergency Management (OLEM) are available on the Community Engagement Initiative website at www.epa.gov/fedfac/community-engagement. Helpful tools and data focused on community engagement at underground storage tank (UST) sites are provided on the EPA's Office of Underground Storage Tanks (OUST) community engagement website at www.epa.gov/ust/community-engagement-and-underground-storage-tank-program. Community engagement plays an important role in the selection and implementation of remedies at Superfund sites. For more information, see *Considering Reasonably Anticipated Future Land Use and Reducing Barriers to Reuse at EPA-lead Superfund Remedial Sites* available at www.epa.gov/superfund-redevelopment-initiative/superfund-redevelopment-policy-guidance-and-resources.

Environmental Impacts and Project Resiliency

To ensure that cleanup methods remain effective and are protective of human health and the environment over the long term, special consideration should be given to current and projected environmental impacts and resiliency to challenging weather conditions when designing a cleanup strategy at Brownfields sites. Communities are often located close to Brownfields and other blighted properties. Incorporating adaptation and mitigation strategies throughout the Brownfields cleanup and redevelopment process can support community efforts to become more resilient to weather-related impacts and more sustainable Brownfields reuse. Implementing green methods in all phases of a project lead to direct reduction of the environmental footprint of site activities. Helpful tools and strategies that can be implemented during the Brownfields cleanup and redevelopment process are provided in the *Climate Smart Brownfields Manual* available at www.epa.gov/land-revitalization/climate-smart-brownfields-manual.

Identifying Funding

One of the most important factors to consider at the beginning of a Brownfields project is funding. Simply put, the project cannot be initiated or undertaken until funding sources are identified and funds are secured. An important factor to the success of a Brownfields project is the ability of the stakeholders to establish a funding strategy that covers the project costs from planning and assessment through cleanup and long-term monitoring. Most Brownfields projects leverage funding from various sources both public and private. Guidance on how to overcome challenges related to finding sufficient funding sources and leverage initial resources to attract additional investments is available at www.epa.gov/brownfields/setting-stage-leveraging-resources-brownfields-revitalization. Be mindful that securing funding can be a lengthy process.

EPA Brownfields Grants

- *Assessment, Revolving Loan Fund and Cleanup Grants (ARC Grants)* fund activities for sites contaminated by petroleum, hazardous substances, controlled substances or mine-scarred land.
- *Area-Wide Planning Grants (AWP)* fund communities for an area affected by Brownfields and promotes area-wide revitalization.
- *Environmental Workforce Development and Job Training Grants (EWDJT)* fund opportunities for local residents to take advantage of jobs created by the assessment and cleanup work of Brownfields sites in the community.
- *Training, Research, and Technical Assistance Grants* provide training, research, and technical assistance to increase community understanding and participation in the Brownfields remediation process.

Learn more about the EPA's Brownfields grants at www.epa.gov/brownfields/types-brownfields-grant-funding. Specific instructions and deadlines for applying for the EPA's Brownfields grants are provided at www.epa.gov/brownfields/apply-brownfields-grant-funding, and information and links for grant resources is available at www.epa.gov/grants/key-grant-resources-applicants-and-recipients.

The range of potential sources and the means of securing funds can appear overwhelming. Fortunately, many helpful resources and tools are available to guide stakeholders in exploring funding options. Funding for the investigation and cleanup of Brownfields sites is available from federal, state, local, and public and private sources. Programs available at the federal level, such as the EPA, typically involve awarding grants and providing technical assistance to communities and stakeholders. Other federal programs, such as the U.S. Department of Housing and Urban Development, the U.S. Department of Agriculture, the U.S. Department of Transportation and the U.S. Department of Commerce, also provide funding and technical assistance for Brownfields projects. State programs are a valuable option as well, as states are increasingly offering flexible tools, financial assistance, tax incentives and other redevelopment support to promote cleanup and reuse of Brownfields sites.

At the beginning of the project, explore federal, state and local programs to learn about the sources of funding available and the process for applying for and securing funding. Take advantage of the many helpful resources available on the EPA Brownfields website (www.epa.gov/brownfields/types-brownfields-grant-funding) to learn about the EPA's grant programs, access to state and tribal response programs, points of contact and success stories.

Key Resource for State Programs

The *2014 State Brownfields and Voluntary Response Programs* report (www.epa.gov/brownfields/2014-state-brownfields-and-voluntary-response-programs) provides information on state environmental, financial and technical programs and tools available for Brownfields projects through state programs.

Cleaning Up Brownfields under State Response Programs -- Getting to "No Further Action" lays out the eligibility requirements and benefits of state cleanup programs that provide guidance, oversight and certain protections from environmental liability. The report describes the process for attaining a state decision or certification of the need for "no further action" for each state program. The report is available at www.epa.gov/brownfields/cleaning-brownfields-under-state-response-programs-getting-no-further-action.

Community Redevelopment

The *2017 Brownfields Federal Programs Guide* describes how the Brownfields Program recognizes that a community's quality of life goes hand-in-hand with economic development and sustainability, and encourages communities to develop and implement their own vision for community revitalization. The guide is available at www.epa.gov/brownfields/2017-brownfields-federal-programs-guide.

The Association of State and Territorial Solid Waste Management Officials (ASTSWMO) *Toolbox for Community Redevelopment* reinforces the state's role in community redevelopment. This toolbox is available at astswmo.org/files/policies/CERCLA_and_Brownfields/2017_Toolbox/2016%20Toolbox%20for%20Community%20Redevelopment.pdf.

Assistance with financing and economic restructuring for Brownfields-impacted communities is available through the Council of Development Finance Agencies (CDFA). Funded through the EPA Brownfields Technical Assistance Program, CDFA provides education, resources, research and networking on revolving loan funds, tax incentives, tax increment finance and other tools available for redevelopment finance. For further information about the CDFA, visit www.cdfa.net.

Obtaining Professional Support

Most decision makers for Brownfields sites will require technical and legal assistance to fully understand the complexities of investigating and cleaning up sites. Depending on the complexity of a particular site, decision makers may need the assistance of the following to perform many of the activities required to investigate and clean up the site:

- environmental practitioners with expertise in geosciences, chemistry, engineering, field sampling, redevelopment and other disciplines;
- analytical laboratories;
- cleanup service providers; and
- technology vendors.

EPA recommends the inclusion of these professionals and other experts as members of a Brownfields project team to ensure the successful completion of the Brownfields project.

EPA partners with nonprofit organizations to provide technical assistance and research resources to help communities and other stakeholders in the assessment and cleanup of Brownfields properties. These organizations operate programs which offer training, research and direct technical assistance to communities and develop tools and materials that communities can use to assist them. This independent resource offers a wide range of expertise. More information can be found at www.epa.gov/brownfields/brownfields-technical-assistance-and-research.

Regulations applicable to Brownfields projects in some states require the participation of certified or licensed environmental professionals to help guide the site investigation and cleanup process. For example, the EPA's final rule for All Appropriate Inquiries (AAI) requires that AAI and Phase I environmental site assessments be supervised by individuals who have specific certification or licensure, education or experience levels that meet the definition of "Environmental Professional" provided in the AAI final rule. More information can be found at www.epa.gov/brownfields/brownfields-all-appropriate-inquiries.

Using Certified Professionals

Some states require the participation of certified or licensed professionals to help guide the site investigation and cleanup process.

Additionally, some states require that certified professional geologists, licensed site professionals or professional engineers oversee various stages of the investigation and cleanup process. A request for proposal (RFP) is often used as the procurement mechanism to obtain the services of certified professionals (individuals or a firm). The RFP requests potential service providers to submit a proposal that addresses the approach, qualifications and cost estimate for the services requested. The RFP can include specifications that encourage prospective bidders to think "outside the box" and consider innovative approaches. Incorporating innovative strategies and technologies into site contracts can help inform decision making and increase project efficiency and effectiveness. Selection criteria outlined in the RFP should include the demonstrated experience of the individuals or firm in developing valid options for using streamlined strategies and innovative technologies at Brownfields sites and in successfully implementing the selected options. Demonstrated experience can include resumes, project descriptions and letters of recommendation.

The Bigger Picture – Related EPA Initiatives

As the EPA Brownfields Program has matured over the years to address new challenges and evolving stakeholder needs, new programs and initiatives have been undertaken to better integrate efforts to clean up and reuse Brownfields sites. See the table below as well as Spotlight 1, Innovations in Contracting, and Spotlight 2, Supporting Tribal Revitalization, for a brief overview of several programs and initiatives that are designed to help the Brownfields community integrate principles such as sustainability, renewable energy, smart growth and innovative methods into revitalization efforts. In addition to setting policy and providing guidelines, these programs offer extensive resources to help Brownfields stakeholders apply lessons learned from the experiences of other redevelopment projects.

Listed below are highlights of several EPA programs and redevelopment initiatives focused on helping Brownfields stakeholders learn how to more efficiently and collaboratively prepare contaminated properties for reuse.

EPA Initiative / Program	Available Resources / Additional Details
Land Revitalization Program – The Land Revitalization Program's mission is to restore land and other natural resources into sustainable community assets that maximize beneficial economic, ecological and social uses and ensure protection of human health and the environment. The Land Revitalization Program promotes sustainable approaches to remediation as the norm across all EPA contaminated land programs, recognizing cleanup and reuse as mutually supportive goals. The program emphasizes that the consideration of anticipated property reuse should be an integral part of cleanup decisions.	Resources, policies and guidance, success stories and details about the program are available online at www.epa.gov/land-revitalization. Links to program-specific information, including details about grant and funding resources, are also provided.
Petroleum Brownfields Action Plan: Promoting Revitalization and Sustainability – The EPA launched this program in 2008 to address the specialized challenges associated with the cleanup and reuse of Brownfields sites with petroleum contamination, such as abandoned neighborhood gas stations. This Action Plan aims to address these challenges by improving stakeholder communication, expanding technical assistance, exploring potential policy changes and building upon existing successes by expanding partnerships.	Visit www.epa.gov/ust/petroleum-brownfields-action-plans to access the Action Plan; progress reports, success stories, grants information and other resources can be found at www.epa.gov/ust/petroleum-brownfields.
Smart Growth – The EPA's Smart Growth program offers strategies to help communities grow in ways that expand economic opportunity while protecting health and the environment. The program provides tools and resources to help people implement sustainable development strategies that promote healthy, attractive and economically strong communities. Integrating community, environmental and economic considerations, applying smart growth principles to Brownfields sites can lead to the selection of more valuable and sustainable reuse alternatives.	To learn more about the EPA's Smart Growth program, visit www.epa.gov/smartgrowth. Resources, tools, technical assistance and examples of successful smart growth approaches are provided.
RE-Powering America's Land – Launched in 2008, this EPA initiative encourages renewable energy development on current and formerly contaminated land and mine sites. Efforts focus on identifying the renewable energy potential of sites and providing useful resources for communities, developers, industry and state and local governments and others interested in reusing these sites for renewable energy development.	Visit www.epa.gov/re-powering for information about funding sources, technical assistance, fact sheets, interactive mapping tools to identify sites with renewable energy potential, webinars and federal and state incentives.
Superfund Redevelopment Initiative (SRI) – Since 1999, SRI has helped communities reclaim and reuse thousands of acres of formerly contaminated land by offering an array of tools, partnerships and activities to provide local communities with new opportunities to grow and prosper. In addition to cleaning up these Superfund sites and making them protective of human health and the environment, the Agency is working with communities and other partners to consider future use opportunities and integrate appropriate reuse options into the cleanup process. The EPA is also working with communities at sites that have already been cleaned up to ensure long-term stewardship of site remedies and to promote reuse.	Webinars, success stories, tools and resources, community support, cleaned up sites that can support reuse, partnership information and complete details about the initiative are available online at www.epa.gov/superfund-redevelopment-initiative.
Community Engagement Initiative (CEI) – Launched in 2009, the CEI was created to enhance the Office of Land and Emergency Management (OLEM) HQ and Regional offices' engagement with local communities and other stakeholders. Furthermore, CEI integrates stakeholders into the decision-making processes related to the cleanup and reuse of sites.	An evaluation of the Initiative published in 2013 focuses on the effectiveness of the OLEM program community engagement activities, and is available at www.epa.gov/sites/production/files/2015-10/documents/ce-eval-report-final.pdf.

Spotlight 1

Innovations in Contracting

The majority of assessment, investigation and cleanup work at Brownfields sites is implemented through contracts to site cleanup professionals. The incorporation of innovative strategies and technologies into Brownfields site contracts gains potentially substantial benefits over conventional methods. Innovative site investigation and remediation strategies and technologies are often cost effective, more efficient than established methods and reduce uncertainty. An innovative technology is a tested process used as a treatment for contaminated materials, but lacks a long-term history of use. In situ chemical oxidation, thermal remediation, enhanced bioremediation and nanoremediation are just a few examples of innovative remediation technologies. Examples of innovative site investigation methods include:

- **Systematic planning process** – a comprehensive, up-front planning process that ensures data collected will lead to informed decision making. The process includes three elements: framing the problem by identifying objectives, constraints, stakeholders, the regulatory framework, and key decisions; developing a conceptual site model that obtains information to support decision making; and evaluating as well as managing uncertainty.
- **Real-time measurement technologies** – any acquisition, analytical or measurement technology that generates data to support real-time decision making, including rapid turn-around from fixed laboratories or field-based measurement technologies.
- **High-resolution site characterization** – strategies and techniques using scale-appropriate measurement and sample density to determine contaminant distributions and the physical context in which they reside with greater certainty, supporting efficient and comprehensive characterization of sites.
- **Incremental composite sampling** – a soil sampling method designed to statistically reduce variability by providing a defensible estimate of the mean contaminant concentration in a volume of soil that is used for decision making.

Nearly every stage of a Brownfields site cleanup project presents an opportunity to integrate innovative strategies and technologies.

- Procurement planning should involve comprehensive planning, developing a procurement plan, project-specific objectives and a technical scope of work that supports incorporation of innovative methods.
- During the RFP stage, stakeholders can encourage bidders to submit alternative, innovative approaches along with traditional ones. Bidders can submit separate cost proposals for the innovative approach so that the cost benefit for both approaches can be considered.
- Individuals preparing RFPs can help service providers propose innovative methods by providing the service providers with all available, non-confidential site information and cleanup and redevelopment goals with the RFP. This information can include Phase I and II ESA reports, as well as U.S. Geological Survey (USGS) reports, soil studies, tax records and utility records.
- After the RFP stage, stakeholders will evaluate proposals. A site should be well-characterized, have no critical data gaps and have established remedy performance criteria before a remediation technology is selected. The service provider should demonstrate a thorough knowledge of potential limitations and problems with proposed technologies.
- Throughout the process, state, tribal and local governments play an important role in facilitating innovation. Their support and cooperation can promote innovative cleanups.

Spotlight 2

Supporting Tribal Revitalization

Federally recognized tribes in the United States develop their own environmental policy, establish standards and manage their environmental protection and natural resource management programs. Tribes can establish an EPA Brownfields program or a Tribal Response Program to address and reuse contaminated lands. The EPA provides technical and financial assistance to tribes for the restoration of contaminated tribal lands and the implementation of more effective approaches to attaining productive reuse of sites. By using the grants and tools available, tribes can achieve their fundamental environmental and revitalization goals and enrich the health and welfare of their communities.

Financial and Technical Assistance Provided by the EPA

- ***Tribal Response Program Grants****:* Section 128(a) Response Program funding can be used to establish or enhance existing response activities associated with Brownfields assessments and cleanup. EPA regional personnel provide technical assistance to tribes as they apply for and carry out cleanup activities at Brownfields sites with these grant funds. In FY2016, EPA allocated more than $12 million to 107 tribes for their tribal response programs.
- ***Technical Assistance to Tribal Communities****:* EPA awarded $2 million in funding over five years to Kansas State University (KSU) in 2017 to provide technical support to tribes addressing Brownfields remediation. Specifically, KSU will assist tribes in identifying solutions on assessing and cleaning up Brownfields, developing reuse plans, and financing options. Furthermore, KSU will help tribes develop peer networks to share ideas about Brownfields issues.

Tribal Highlights

- The **Mille Lacs Band of Ojibwe (MN)** used Section 128(a) Response Program funding to assist with environmental assessment activities and a feasibility analysis to determine if six former wastewater treatment lagoons could support fish rearing. This led to the conversion of the lagoons into a walleye fish hatchery, which produced 1.3 million walleye fry in its first year of operation (2016). This project, with assistance from the U.S. Fish and Wildlife Service, led to 12,000 walleye fingerlings used to stock tribe and local lakes which helps boost the local economy and serves as a source of food.

- After the EPA provided Targeted Brownfields Assessment support to characterize buildings and cleanup costs, the **Spirit Lake Tribe (ND)** used Section 128(a) Response Program funding to conduct cleanup activities at five abandoned homes in 2016. Located in Sheyenne, North Dakota, these former residential structures were vacated due to asbestos and overall poor condition, and were demolished after cleanup to provide space for new and safe housing.

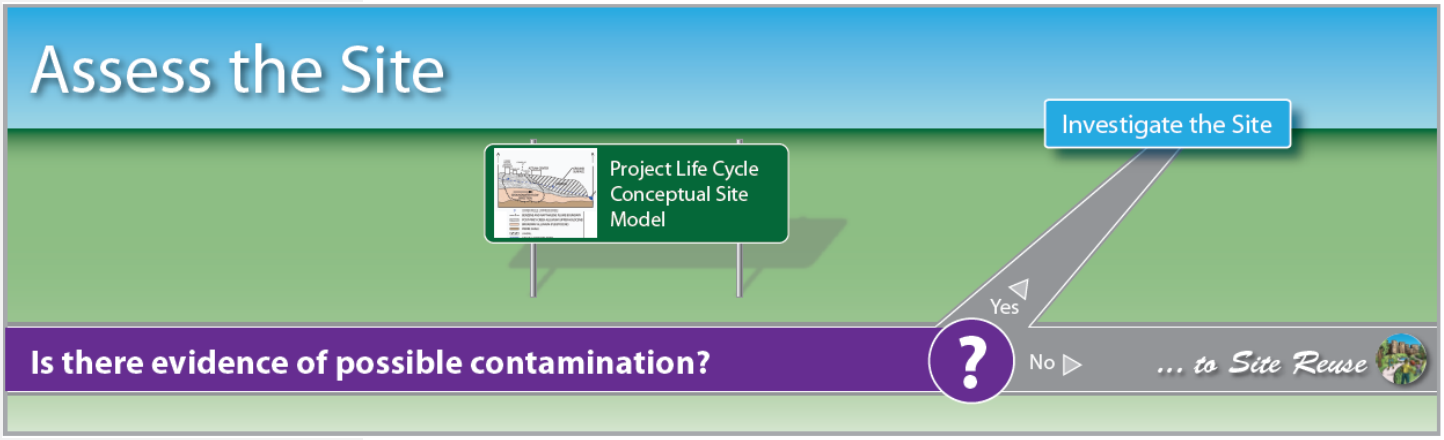
- In response to extensive environmental degradation from illegal marijuana cultivation on its Reservation lands, the **Yurok Tribe Environmental Program (CA)** is using Section 128(a) Response Program funding to document unpermitted water diversion, lack of proper sanitation facilities, pesticide usage, illegal road building and land clearing and improper disposal of solid and hazardous waste. The Tribe hired a dedicated environmental enforcement officer to conduct water quality sampling on affected waterways and enforce tribal ordinances.

- The **Tanana Chiefs Conference (AK)**, an Alaskan Native non-profit corporation dedicated to the needs of tribal members, has used Section 128(a) Response Program funding since 2015 to build significant capacity among its membership. They offer support for training and their Tribal Response Program helps tribes address Brownfields in their community and achieve successful remediation.

- The **Lower Brule Sioux Tribe (SD)** used $200K in Brownfields grant funds to clean up environmental contamination at the Old Housing Authority Building property in the center of the Lower Brule Community. Once cleanup was complete, the Tribe used the location as the site of a new Boys and Girls Club for Reservation youth.

For More Information

Additional Brownfields tribal program updates can be found in the quarterly newsletter “State and Tribal Response Program Highlights” accessible at www.epa.gov/brownfields/brownfields-state-tribal-program-updates. For grant funding guidance and publications, visit www.epa.gov/brownfields/brownfields-state-local-tribal-information.



The site assessment is a crucial step in the Brownfields process because the need for any further environmental investigation and cleanup will depend on whether potential environmental concerns are identified.

Collect and Assess Information about Your Brownfields Site

The purpose of this phase is to evaluate the potential for contamination at a particular site by collecting and reviewing existing information. A site assessment includes a review of site and government records and a site visit that includes visually inspecting the site, as well as adjacent areas, to assess current conditions and identify any potential releases of hazardous substances. In addition, the site visit includes interview people who have direct knowledge about historical uses of the site, including past and current operational practices and any potential for related environmental concerns.

ASTM International Phase I ESA

The site assessment is usually conducted consistent with ASTM International Phase I ESA practices, which are the generally accepted standard for evaluating a site for a potential release of hazardous substances or petroleum products into site structures, soil, groundwater, surface water, sediment and indoor air.

Each instance when the available information suggests that a release of hazardous substances or petroleum products may have occurred is designated as a recognized environmental condition (REC).

For more information about the ASTM International standard practice, visit www.astm.org/Standards/E1527.htm.

A site assessment—typically beginning with a Phase I Environmental Site Assessment (ESA)—is essentially a compilation and review of available information. This is an essential step in the process of environmental due diligence, the process of assessing the extent of contamination at the site. Efforts conducted during a site assessment to evaluate the history of a site and determine whether contamination is present also can be used to comply with the requirements of an All Appropriate Inquiries (AAI) investigation. The 2002 Brownfields Amendments to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), also known as Superfund, required EPA to promulgate regulations establishing standards and practices for conducting AAI. The AAI final rule was published in the *Federal Register* on November 1, 2005 (70 FR 66070) and went into effect on November 1, 2006. Conducting an AAI investigation is one element required for obtaining liability protection and certain EPA grants.

AAI is the process of evaluating a property's environmental conditions and assessing potential liability for any contamination. AAI investigations are required to be performed for a future property owner to be considered a bona fide prospective purchaser, innocent landowner or contiguous property owner under CERCLA.

AAI investigations must be performed within a certain time frame and by individuals who have specific certification or licensure, education or experience levels that meet the specified definition of “Environmental Professional” provided in the AAI final rule. AAI requirements may be met using ASTM E1527-13 “Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process” and E2247-16 “Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process for Forestland or Rural Property.” ASTM is an international standards organization, and both standards are consistent with the requirements of the final rule and can be used to satisfy the statutory requirements for conducting AAI. Additional information on the AAI process and ASTM standards can be found online at www.epa.gov/brownfields/brownfields-all-appropriate-inquiries.

During the site assessment phase, it is important to consider the activities and requirements described in the subsequent sections of this Road Map and determine how the initial site assessment information may affect them. Because the information obtained in this phase will determine whether any future site investigation work will be needed at the site, assessment activities should be thorough and tailored to meet site- and project-specific data objectives. The information collected during this initial phase of the Brownfields project is extremely important for providing early indications of whether the property may need to be cleaned up to support its intended reuse and can provide a preliminary indication of the available cleanup technologies. In addition, the assessment can provide early indications of whether the planned reuse may be feasible.

The information collected about the site is typically organized into a project life cycle conceptual site model (CSM). Leveraging existing data is essential to developing the CSM. The CSM is a valuable planning tool and framework for designing site activities and facilitating communications within the project team and with stakeholders. The CSM is also fundamental to the design of potential field sampling decision points. Making the best use of existing data can result in a more powerful CSM, leading to better informed planning and decision making. See Spotlight 3, Project Life Cycle Conceptual Site Model, for details and examples of CSMs.

Community Benefit

The CSM is useful for sharing information with community members about the environmental conditions of the site, goals for the cleanup, data to be collected and decisions to be made.

The needs and concerns of the community are also important considerations at this early step. For example, it may be beneficial to develop social and economic profiles and clearly identify what the community considers to be acceptable environmental risks. Discussions and planning for how to identify stakeholders and keep them engaged and actively participating throughout the entire project are important activities to be undertaken in conjunction with site assessment.

Consider These Questions

Goals and Planning

- Has a redevelopment plan been prepared or a proposed end use identified?
- Is a residential development planned?
- If located in an industrial area, will the site remain industrial or be rezoned for commercial use?
- If the site shows evidence of contamination, who and what will be affected?
- Will users of the property be exposed directly to the site soil, soil vapor, sediment or surface water?
- Who will conduct long-term monitoring and oversight, particularly if residual contamination is left in place?

Oversight

- Is the site located in an area targeted for redevelopment? If so, is the site being considered for cleanup under a federal or state Superfund cleanup initiative?
- Will the site be entered into a VCP? If not, what agency (federal, state, local or tribal) is responsible for managing oversight of cleanup?
- Are there other federal, state, local or tribal regulatory requirements for site assessment?
- Are there other regulatory requirements for specific contaminants likely to be present on the site (for example, lead-based paint or asbestos)?

Although not required by the ASTM Phase I ESA standard or AAI, technologies that evaluate the potential for environmental conditions to impact air and building material may be applicable at this stage, as well as some real-time measurement technologies useful for assessing contamination in soil, groundwater, surface water or other environmental media. For example, ASTM E2600-15 "Standard Guide for Vapor Encroachment Screening on Property Involved in Real Estate Transactions" provides guidance on conducting a vapor encroachment screen with respect to chemicals of concern at a property. This standard can be viewed at www.astm.org/Standards/E2600.htm. Examples of sampling and analysis technologies used to characterize and monitor a site before and throughout the remediation process can be found at the end of this document in Appendix D (Guide to Contaminants and Technologies). However, the use of technologies is limited, since much of the work at this phase typically involves a search for paper and electronic records and interviews with current and previous site owners and workers.

Conduct Your Site Assessment

Typical activities that may be conducted during the site assessment phase are indicated below. The list is intended as a general planning guide and is not a comprehensive listing of assessment activities required under state and federal regulations. Factors that should be considered are presented in the margin in the form of questions. For a better understanding of these requirements, such as the EPA's AAI regulations, consult the references identified and work with appropriate regulatory authorities.

- Establish a core technical team and evaluate the adequacy of existing site information and identify potential releases of hazardous substances or petroleum products.
  - Identify and secure experts in geosciences, chemistry, engineering, regulatory and field sampling.
  - As required, consider additional support from individuals experienced in risk assessment, biology, data management and quality assurance.
- Ensure that all Brownfields stakeholders (such as regulators, community members, property owners and technical staff) are involved in the decision making process.
- Identify future goals and reuse plans for the site.
- Explore options for funding and technical assistance from the EPA.
  - Consider applying for a Brownfields assessment grant.
  - Request technical assistance from the EPA's Targeted Brownfields Assessment (TBA) program.
- Assess the site using the ASTM International Phase I ESA standard or its equivalent (refer to the Federal Regulations for standards for conducting AAI) and conduct AAI to determine whether contamination is likely present on site.

An Environmental Professional will perform a records search, visit the site and interview individuals with knowledge of the site to identify recognized environmental conditions (RECs). The effort includes the following activities:

- Search relevant environmental databases. Search federal and state databases, including but not limited to: (1) the EPA's Superfund Enterprise Management System (SEMS) of potentially contaminated sites, (2) RCRAInfo, a national program management and inventory system of hazardous waste handlers, (3) the National Pollutant Discharge Elimination System (NPDES) of permits issued for discharges into surface water and (4) state records of "emergency removal" actions (for example, the removal of leaking drums or the excavation of explosive waste). There are also commercial services available to conduct database searches on a fee basis.
- Identify past owners and uses of the property by conducting a title search and reviewing tax documents, fire insurance maps, city directories, sewer maps, topographic maps, aerial photographs and fire, policy and health department documentation related to the property.
- Analyze local government and other historical records to identify past use or disposal of hazardous or other waste materials at the site.
- Interview current property owners, occupants and others associated with the site, such as previous owners, occupants and employees.
- Conduct a walkthrough inspection of the site and a visual inspection of adjacent and other local properties to identify RECs.

- Although not required as part of a Phase I ESA, consider collecting samples to test for the presence of various contaminants—for example, lead-based paint, asbestos and radon in structures.
- Plan additional investigations at the site and collect information as necessary to investigate any releases of hazardous substances identified during the site assessment and resolve any other uncertainties related to the site.
- Identify existing sources of information to help develop the initial CSM including reviewing site information, conducting a comprehensive search for site documentation, performing a site walkover and requesting input from the EPA and state and tribal representatives.
- Coordinate with the project team to begin development of the project life cycle CSM.
- Review the applicability of government oversight programs:
  - Determine whether there is a state voluntary cleanup program (VCP) and consult with the appropriate federal, state, local and tribal regulatory agencies to include them in the decision-making process as early as possible.
  - Select the approach (such as redevelopment programs, federal regulatory programs, property transfer laws or a state Brownfields program) that is required or available to facilitate the cleanup of the site.
  - Identify whether economic incentives, such as benefits from state Brownfields programs or federal Brownfields tax deductions, can be obtained.

Consider These Questions

(continued)

The Community

- What are the special needs and concerns of the community?
- How can meaningful community involvement be solicited?
- What environmental standards should be considered to ensure that community stakeholders are satisfied with the outcome of the cleanup?

Site Conditions

- What is known about the site?
- What records exist that indicate potential contamination and past use of the property and adjacent properties?
- What information is needed to identify the types and extent or the absence of contamination?
- Has a previous Phase I ESA been conducted?
- Have other environmental actions occurred (such as notices of violation)?

Funding

- Who will pay for the site investigation and cleanup?
- Are private, state, city or other federal agency funds available?

    - Contact the EPA regional Brownfields coordinator to identify and determine the availability of EPA support programs and federal financial incentives.
- Decide how to encourage and incorporate community participation:
    - Identify regulatory requirements for public involvement.
    - Assess community interest in the project.
    - Identify community-based organizations.
    - Review any community plans for redevelopment.
- Examine factors and hurdles that may impede redevelopment and reuse.
- Identify environmental or other site conditions that the community would likely find unacceptable in light of the proposed reuse.
- Begin identifying potential sources for funding site investigation and cleanup activities at the site, if necessary.

Plan Your Next Steps

The next course of action is determined by the results of the site assessment and what has been learned about the site. The steps to investigate and cleanup of Brownfields sites are not linear and may involve cycles of information that evolve and define the most efficient redevelopment approach. Several possible outcomes and subsequent courses of action are explained below.

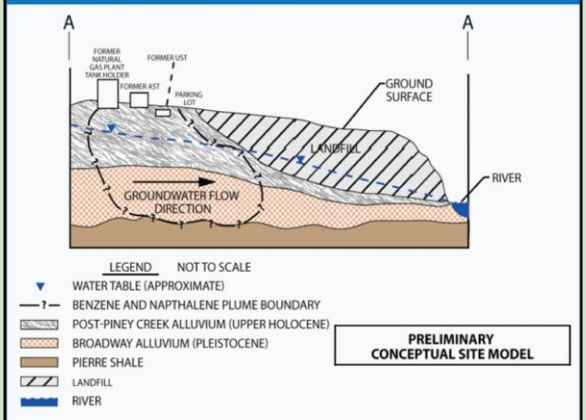
Result of Site Assessment	Course of Action
No evidence of contamination is found and there is no evidence of possible contamination. Stakeholder concerns have been addressed adequately.	Confirm results with appropriate regulatory officials before proceeding with redevelopment activities.
Evidence of contamination is found that poses a significant potential risk to human health or the environment.	Contact the appropriate federal, state, local or tribal government agencies responsible for hazardous waste. Based on feedback from the government agency, identify the cleanup levels required for redevelopment, and proceed to the Investigate the Site phase.
Contamination possibly exists, as indicated by the presence of RECs.	Proceed to the Investigate the Site phase.
Contamination definitely exists, but no site investigation has been conducted.	Proceed to the Investigate the Site phase.
Contamination definitely exists and a site investigation has been performed.	Evaluate the CSM for data gaps. Collect ancillary data and re-evaluate if enough information exists to allow development of cleanup selection options. Proceed to the Investigate the Site phase if additional investigation is warranted; otherwise, proceed to the Assess and Select Cleanup Options phase.

Spotlight 3

Project Life Cycle Conceptual Site Model

A Conceptual Site Model (CSM) is an interactive graphical and/or written summary of what is known or hypothesized about environmental contamination at a Brownfields site. An effective CSM is easy to understand and helps technical teams, communities and stakeholders communicate with each other and learn about the nature, extent, exposure and risk associated with contamination. CSMs typically include graphical data and written content, and may also include information such as site features, geologic and hydrogeologic data, contaminant types, transport and exposure pathways and potential receptors.

EXAMPLE: Preliminary CSM



Benefits of CSM Use

CSMs are an important tool for the assessment and cleanup of Brownfields sites because they help stakeholders:

- More fully understand site conditions and features
- Synthesize information from multiple sources
- Identify which information is unknown or uncertain about the site
- Define a plan for collecting additional information
- Obtain agreement on site conditions and related project investigation, design and cleanup plans

Phases of the Project Life Cycle CSM

There are six phases of a life cycle CSM. It is important to understand that a life cycle CSM does not require the creation of six individual CSMs, but rather the development of one CSM that evolves through all stages of site redevelopment. As additional information about the site is known, the CSM becomes a powerful tool to support technical and communication needs.

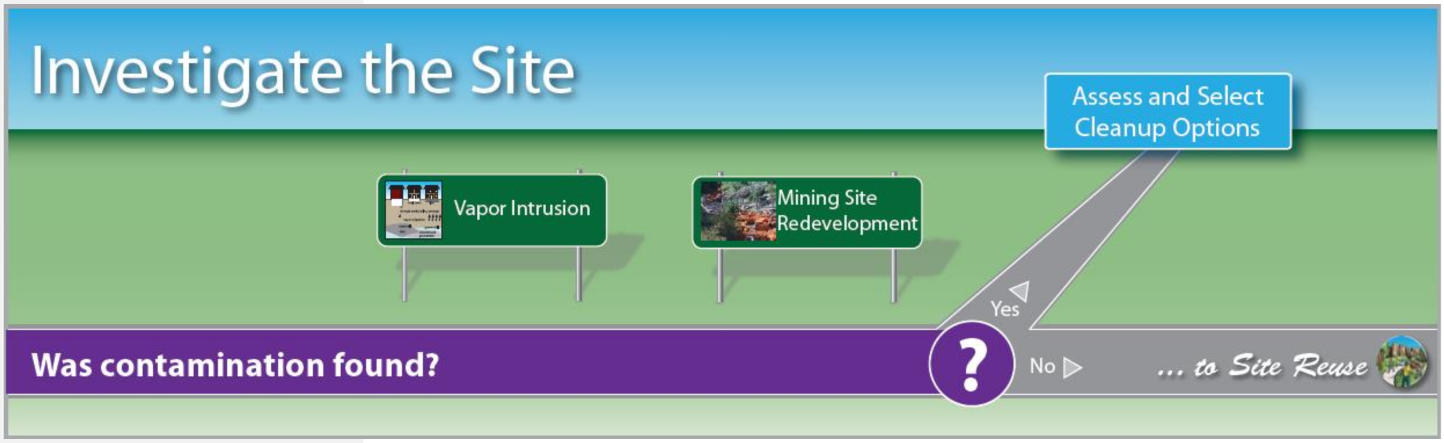
Project Life Cycle CSM Phases

Preliminary	Baseline	Characterization Stage	Design Stage	Remediation / Mitigation Stage	Post-Remedy Stage
Initial version of the CSM developed using existing data such as historical information, interviews with site owners, information from databases managed by third parties and other important background information.	A refined version of the Preliminary CSM used to identify data gaps and areas where uncertainties exist, such as exposure pathways and receptors. The data gaps and uncertainties serve as the basis for developing detailed plans for site investigation.	Adds to the CSM information obtained during site investigation, which is used to help select appropriate remedial strategies and technologies.	Incorporates into the CSM information at a more detailed level, or new considerations that are identified, in support of the development of a site-specific remedial design.	Information obtained during remedy implementation is added, resulting in a CSM that is used to support efforts to optimize remediation effectiveness.	CSM includes information obtained from the construction and completion of the remedy, such as contamination left on site, institutional controls (ICs) that have been implemented and monitoring requirements.
Assess the Site		Investigate the Site → Assess and Select Cleanup Options	Design and Implement the Cleanup		

Road Map Steps: The six life cycle CSM phases relate to the general steps involved in the investigation and cleanup of a brownfields site.

For More Information

More details, including tools to assist in developing and using a CSM, and examples of CSMs, are available at www.clu-in.org/optimization/components_csm.cfm.



Information collected during the site investigation phase supports future decisions about potential cleanup options and reuse alternatives.

Confirm Contamination and Identify its Source, Nature and Extent

Activities conducted during the site investigation phase are focused on confirming whether any contamination exists at a site, locating the source of contamination, characterizing its nature and extent and identifying possible threats to the environment or to any people living or working nearby. The investigation also forms the basis for the strategy and design of the cleanup for the site. For Brownfields sites, the results of a site investigation are used to identify and quantify the risks associated with potential contamination and to develop effective cleanup plans. The results are also used to set specific goals for the cleanup and assess anticipated cleanup costs, which will help stakeholders evaluate the economic viability of the redevelopment project. In total, the investigation will support a number of key decisions. Before starting the investigation, the project team should identify the data needs for the decisions and carefully plan the investigation to meet those needs.

ASTM International Phase II ESA

ESAs are conducted to evaluate existing environmental problems from past operations and potential environmental problems from current or proposed operations at a site. The primary objective of conducting a Phase II ESA is to confirm and evaluate the RECs identified in the Phase I ESA.

For more information about the ASTM International standard practice, visit www.astm.org/Standards/E1903.htm

A site investigation, also referred to as a Phase II ESA, is designed based on the results of the Phase I ESA discussed in the preceding section. The Phase II ESA may include the analysis of samples of building materials and environmental media, such as soil, soil gas, groundwater, surface water, sediment and indoor air. For sites where contamination is confirmed, site investigation efforts are used to delineate the source locations, nature and extent, and significance of contamination for the purpose of supporting subsequent cleanup and reuse decisions. Contaminant migration pathways through media (for example, soil, groundwater and air) are also examined in relation to potential human and environmental (animal and plant) receptors. A baseline risk assessment to quantify risk to human health and or the environment may be conducted. Examples of investigation technologies that may be useful during this phase are presented at the end of this document in the Investigative Technologies section of Appendix D (Guide to Contaminants and Technologies).

Many technologies are available to assist those involved in Brownfields redevelopment to be more effective in their site investigation efforts. Several BMPs for site investigation and cleanup have emerged in the last few years. These BMPs incorporate systematic project planning, dynamic work strategies and the use of real-time measurement technologies to accelerate and improve the cleanup process by reducing costs, improving decision certainty, and expediting site redevelopment. For example, effective systematic planning of the investigation can result in lower overall project costs, while dynamic work strategies can save time and reduce or eliminate the need for multiple mobilizations to a site to complete investigations.

Successful Brownfields projects rely on environmental data that accurately represent actual site conditions and result in a robust CSM of observed conditions. This, in turn, helps to reduce uncertainty about the site conditions. In order for a Brownfields project to be able to proceed in a manner that is acceptable to all stakeholders and in accordance with government regulatory and oversight programs (for example, EPA quality assurance and state voluntary cleanup programs), the data must be high quality and defensible and provide sufficient detail to support robust decision-making.

Real-time measurement technologies provide information about contamination at the site that the project team can analyze while in the field. Using real-time direct sensing tools and field-based analytical methods is a cost-effective way to help reduce site uncertainty and provides a more precise picture of the conditions at the site. These tools and methods increase sampling density and precision by enabling lower per-measurement costs than sole reliance on conventional sampling and laboratory analysis methods. In addition, they can also increase the quality and value of conventionally derived data by ensuring that samples are collected from the appropriate locations, thereby increasing the representativeness of those samples. Project teams can use data collected with field-based methods to make timely decisions rather than waiting for laboratory results and formal project report generation which can take weeks to months

Information about data quality is available at www.triadcentral.org/reg, including an overview of key concepts and considerations for using real-time

Types of Uncertainty

Using BMPs helps reduce a variety of uncertainties associated with Brownfields projects.

Analytical Uncertainty
Methods, Quantity, Quality, Validation, Appropriate Use

Sampling Uncertainty
Media, Methods, Location, Distribution, Depth, Purpose

Site Decision Uncertainty
Risk, Action Levels, Remedy, Stakeholders, Acceptability

Resource Uncertainty
Funding, Schedule, Personnel, Logistics, Weather

Real-time Measurement Systems

Real-time measurement systems include:

- *Sample acquisition technologies* - direct push technologies equipped with sensor probes for acquiring subsurface information and Global Positioning System (GPS) technologies that quickly and easily establish locational control in the field.
- *Analytical methods* - X-ray Fluorescence (XRF), portable gas chromatograph and mass spectroscopy (GC-MS) technologies, and immunoassay test kits used in the field.
- *Data analysis/decision support tools* - database systems, Geographic Information Systems (GIS), data visualization packages and data reduction tools that support in-field decision making.

Field based methods can be very powerful by:

- Reducing uncertainty and improving the understanding of site conditions with greater sampling density.
- Offering lower per-measurement costs than conventional sampling and laboratory analysis.
- Supporting real-time decision- making based on CSM rather than waiting for laboratory results and formal reports.
- Increasing decision confidence of stakeholders.

measurement systems. Additional resources are provided by the Interstate Technology and Regulatory Council (ITRC) Incremental Sampling Methodology Team (www.itrcweb.org/teampublic_ISM.asp) and the ITRC Sampling, Characterization and Monitoring Team (www.itrcweb.org/teampublic_SCM.asp).

Reducing uncertainties in the CSM can be accomplished with the implementation of high-resolution site characterization (HRSC) strategies and techniques. Using scale-appropriate measurements and sample density to define contaminant distributions and placement with greater certainty, HRSC leads to faster and more effective site cleanup. HRSC supports more effective use of certain cleanup methods including in situ remedies by:

- Characterizing subsurface conditions critical to successful remedy design at a scale that conventional investigation methods are unable to attain.
- Providing greater confidence that a site is fully characterized by increasing data density.
- Enabling more accurate estimation of contaminant mass and volume through tighter source identification and delineation.
- Improving the cost and performance of remedy monitoring by minimizing monitoring network needs.

As a targeted strategy or as an overall BMP, HRSC can be applied to sites of any size under any regulatory program. Provided below is an overview of using BMPs to investigate a Brownfields site and the benefits of their use.

Best Management Practices for Investigating a Brownfields Site
Linking Decisions, Data and Technologies

Decisions to be Made

Preliminary Planning
- What are the site redevelopment goals?

Systematic Planning
- What decisions are needed to support site goals?
- What information is needed to make decisions?
- What level of data quality is required?
- What data gaps or uncertainties exist?

Work Plan Development
- How should data be collected?
- What are the appropriate sampling and analysis designs to generate data of acceptable quality?
- Can real-time measurement technologies be used to collect data at the level of quality required?

Investigation Using Dynamic Work Strategies
- What do the data indicate?
- Is the delineation of contamination complete?
- Can robust decisions be made?

Project Planning and Technical Performance	Project Life Cycle CSM
Preliminary Planning	Create CSM (Preliminary)
Systematic Planning	Update CSM (Baseline)
Work Plan Development Based on data gaps identified in the Baseline CSM	
Investigation Using Dynamic Work Strategies Conduct additional dynamic sampling as needed	Update CSM (Characterization Stage)
Investigation Complete Take appropriate action based on the decisions made.	Update CSM to support remedy selection, design and implementation

Benefits of Using BMPs
- Improved site investigation information to support better redevelopment decisions
- More effective communication with stakeholders and the local community
- Increased confidence (reduced uncertainty) that cleanup plans are protective of human health and the environment
- Achievement of cleanup goals faster and at lower cost

Additional information on how CSMs build stakeholder consensus and satisfy required objectives is available at www.epa.gov/remedytech/environmental-cleanup-best-management-practices-effective-use-project-life-cycle.

Conduct Your Site Investigation

The development of a Work Plan is critical to a successful site investigation. A Work Plan addresses data gaps identified in the CSM, and includes information on data sampling and analysis methods, and the required data quality. Specifically, the Work Plan should include a Field Sampling Plan (FSP) and Quality Assurance Project Plan (QAPP). The FSP outlines the objectives, rationale and procedures for collecting and analyzing environmental samples. The QAPP describes the necessary quality assurance procedures, quality control activities and key project personnel, providing a clear and complete plan for the environmental data operation and its quality objectives. Altogether, the Work Plan documents the procedural and analytical requirements for Brownfields projects.

What is a data gap?

A data gap identifies the information that is missing from a CSM and indicates the data needed to arrive at a successful management and control measure.

The following lists the activities that are typically conducted during the site investigation phase. This list is intended as a general planning guide and is not a comprehensive inventory of all site investigation activities required under state and federal regulations. Factors to be considered while planning the site investigation are presented in the margin in the form of questions.

- Contact the EPA regional Brownfields coordinator to explore the potential for the project to qualify for a Brownfields assessment grant and options for technical assistance through the EPA's TBA program.
- If a Phase II ESA is needed, contact your state's Brownfields program representative and EPA regional coordinator to identify the availability of state and federal support programs, financial incentives, and funding sources for site investigation and cleanup activities.
- In collaboration with stakeholders, use the results of the Phase I ESA to update the project life cycle CSM. Identify critical data gaps as the basis for the design of a Phase II ESA.
- Identify and consult with the appropriate federal, state, local and tribal agencies to include their input as early as possible in the project, including during the development of the Work Plan. Continue to work with regulatory agencies during the site investigation design and data collection phases to ensure that regulatory requirements are being properly addressed.
- Invite community members to participate in discussions about the project goals and objectives and in decisions about the site investigation design.
- Identify the proper mix of real-time measurement technologies, innovative sampling approaches (such as incremental sampling) and conventional methods

Consider These Questions

Goals and Planning

- Can the need for cleanup be assessed accurately from the site assessment or from a previous site investigation?
- Who or what could be affected by the contamination or cleanup efforts?
- What happens if contamination poses a "significant threat" to local residents?
- What happens if the contamination is originating from an adjacent property or other off-site source?
- What happens if sampling indicates that contamination is originating from a naturally occurring source?

Oversight

- Will the site be entered into a state Voluntary Cleanup Program (VCP)? If so, will the investigation plan be reviewed through the VCP? If not, are there applicable federal, state, local and tribal regulatory requirements?
- Which agency will oversee the investigation? Does the agency have suitable standards or guidelines for the proposed reuse?

The Community

- What issues has the community raised that may affect the site investigation?
- How will the results of the site investigation be shared with the community?

(such as off-site laboratory analysis) to investigate the site and meet the required level of data quality.

- Research and ensure that proposed field-based and off-site laboratory analytical methods can accurately detect all contaminants of interest to a concentration that is lower than or comparable to the screening level concentrations defined by the regulatory guidance and the agencies overseeing the project.

Incremental Sampling

Incremental sampling methodology (ISM) is a structured composite sampling and processing protocol for soils that provides representative samples of specific soil volumes by collecting numerous increments of soil that are combined, processed and subsampled according to specific protocols. ISM reduces data variability and improves the reliability and defensibility of sampling data. More information is available at www.itrcweb.org/Team/Public?teamID=11

- Conduct the Phase II ESA to define the environmental conditions associated with the identified RECs at the site:
  - Identify potentially viable site sampling and testing methods to confirm geological and hydrogeological site conditions. For example, consider consulting with a geophysical survey service provider to evaluate approaches for cost-effectively addressing data gaps.
  - Confirm and refine as necessary the human health and ecological pathways for exposure to site contaminants.
  - Delineate the nature, extent, source and significance of any contamination confirmed to be present.
  - During the field investigation, evaluate results with other stakeholders to achieve consensus that the associated data needs at each identified release have been addressed.
  - If applicable, evaluate whether and how the infrastructure systems (for example, roads, sewers and structures) are affected by contamination.
- Update the Baseline CSM with data and observations obtained during the Phase II site investigation.
- Assess the risks posed to human health and the environment. Depending on the planned end use of the property, other potential exposure pathways or sensitive receptors may also require evaluation. Consider the human exposure pathways of direct contact, ingestion or inhalation of soil and dust, water and indoor air.
- Depending on state regulatory requirements, perform a risk assessment to identify site-specific cleanup levels when contaminant concentrations confirmed at the site exceed regulatory screening levels.
- Use the Characterization CSM to identify and evaluate potential cleanup options.
- Evaluate confirmed site contamination in all affected environmental media in terms of overall cleanup costs, including initial actions and long-term operation

Consider These Questions

(continued)

Site Conditions

- What are the potential exposure pathways?
- Are the infrastructure systems (roads, buildings, sewers, public water systems and other facilities) contaminated? Could they be affected by efforts to clean up contamination?
- Is the site likely to be a “challenging cleanup”? See Spotlight 9.

Options

- Has the team explored the full range of investigation approaches that can produce data of the quality required?
- What real-time technologies are available to facilitate site investigation and support data collection efforts?
- Can the technologies selected limit the number of mobilizations to the site?
- Will the site investigation involve iterative steps to address data gaps that arise during the project?

and maintenance. Include potential cleanup options and constraints that may affect redevelopment requirements, such as project schedules, costs and potential for achieving the desired reuse.

- Share the updated CSM with members of the community to promote understanding of the site conditions.

Real-Time Sampling Equipment

A handheld X-ray fluorescence (XRF) instrument used to screen soil for contamination (*left).* XRF instruments are field-portable devices for simultaneously measuring metals and other elements in various media. The instrument provides a real-time display of the detected contaminant and concentration. XRF devices provide data in the field that can help identify and characterize contamination and guide cleanup work.

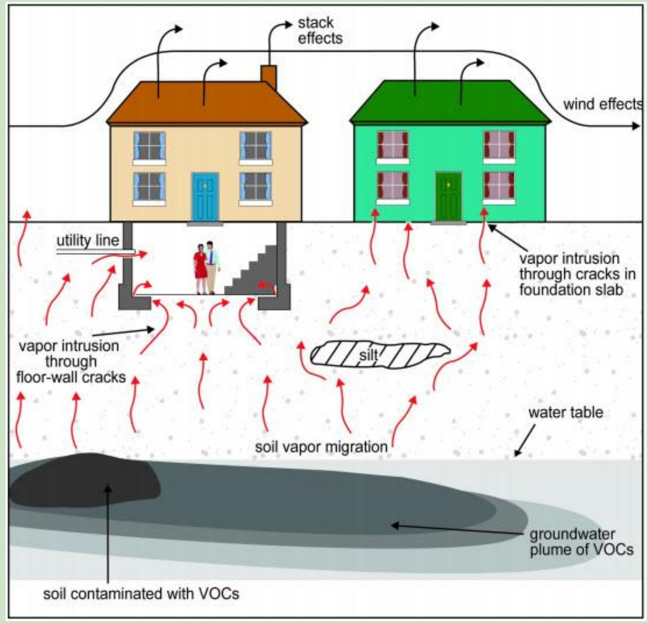
Plan Your Next Steps

As discussed in the Introduction section, the Road Map lays out the cleanup process in a linear manner. In reality, the "investigation" activities occur throughout the process as the life cycle CSM (Spotlight 3 in the previous section) evolves as more is learned about the site. The need to collect data to address data needs realized later in the process may or will require additional data collection. The tools in this section are useful through the process and whenever additional data collection is needed to support informed decision-making. The next course of action is determined by the site investigation results. Several possible outcomes and subsequent courses of action are explained below.

Result of the Site Investigation	Course of Action
No contamination is found.	Consult with appropriate regulatory officials before you proceed with redevelopment activities.
Contamination is found, but does not pose a significant risk to human health or the environment.	Consult with appropriate regulatory officials before you proceed with redevelopment activities.
Contamination is found and likely will require a small expenditure of funds and time for cleanup.	Proceed to the Assess and Select Cleanup Options phase.
Contamination is found and will require a significant expenditure of funds and time for cleanup. Residual contamination is determined not to pose a risk to local residents or the environment.	Determine whether redevelopment continues to be practicable as planned, or whether the redevelopment plan can be altered to fit the circumstances; if so, proceed to the Assess and Select Cleanup Options phase.
Contamination is found that poses a risk to local residents or the environment.	Contact the appropriate federal, state, local or tribal government agencies responsible for hazardous waste. Compliance with other programs, such as the EPA's RCRA and Superfund programs, may be required.

Spotlight 4

Vapor Intrusion



Vapor Intrusion (VI) occurs when there is a migration of vapor-forming chemicals from any subsurface source into an overlying building or structure. The vapors can come from chemicals in contaminated soil or groundwater, and can enter buildings through cracks in basements and foundations, as well as through conduits and other openings in the building envelope (e.g., gaps around pipes and utility lines). People may come into contact with hazardous vapors while performing their day-to-day indoor activities. Chemicals that accumulate at low concentrations in occupied buildings may pose an unacceptable health risk due to long-term or chronic exposure. In extreme cases, vapors may accumulate in dwellings to levels that may pose acute health effects or near-term safety hazards (e.g., explosion).

Contaminants in the subsurface can become sources for VI if they volatilize under normal temperature and pressure conditions. Common vapor-forming chemicals may include volatile organic compounds (VOCs) (e.g., trichloroethylene and benzene); select semivolatile organic compounds (e.g., naphthalene); some polychlorinated biphenyls and pesticides; and elemental mercury.

Careful consideration of the VI pathway is warranted at sites where these vapor-forming chemicals are present in the subsurface. Typical Brownfields sites with VI concerns include (but are not limited to) former gas stations, dry cleaners, landfills, automobile repair shops and former manufacturing and chemical processing plants. However, because contaminated vapors can migrate laterally in the soil, or within groundwater or in conduits, the source does not need to be on the property to create a VI risk. Green spaces or properties with no history of industrial activity may be affected by VI if they are located near a contaminated property.

Considerations for Brownfields Projects

- Evaluating the potential for VI should begin early in the site assessment and investigation phases. Solutions may be easier to implement and are generally less expensive if VI concerns are evaluated before construction is complete.
- The project life cycle CSM should incorporate VI concerns to help define data quality objectives and identify considerations for the cleanup design.
- Strategies to reduce or eliminate VI threats include:
  - Remediating or controlling the source(s) of contamination in the subsurface
  - Installing engineered exposure controls in new or existing buildings, such as sub-foundation ventilation or depressurization systems, which can interrupt soil gas intrusion into the occupied spaces of the building (i.e., mitigate vapor intrusion)
  - Ventilating the affected buildings with properly operated heating, ventilation and air conditioning systems or using non-mechanical means
  - Restricting the use of the property and/or onsite buildings and facilities through institutional controls
  - Changing the location or altering the design of future buildings
- Operation, maintenance and monitoring of remediation systems and engineered exposure controls are generally necessary.
- Some states have specific VI guidance that pertain to their Brownfield cleanup programs; pertinent environmental agencies should be consulted to ensure that up-to-date and appropriate guidance is followed.

For More Information

Technical guides are available with information about investigating and addressing VI, including *Standard Guide for Vapor Encroachment Screening on Property Involved in Real Estate Transactions* (www.astm.org/Standards/E2600.htm) and *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* (www.epa.gov/vaporintrusion/technical-guide-assessing-and-mitigating-vapor-intrusion-pathway-subsurface-vapor).
The EPA's VI website, www.epa.gov/vaporintrusion, provides basic information and policy, guidance, and technical documents. VI resources are also provided on the CLU-IN website at www.clu-in.org/issues/default.focus/sec/Vapor_Intrusion/cat/Overview/.

Spotlight 5

Mining Site Redevelopment

Cleanup of contaminated mining sites as a part of Brownfields redevelopment can be a challenge due to potentially complex site history and substantial environmental issues. The major sources of contamination associated with these sites include mine drainage, waste rock, tailings and ore stockpiles. Other potential sources of contamination include waste generated from machine maintenance operations, vehicle repair, or other activities involving the use of solvents, petroleum, lubricants and other industrial chemicals.

Stakeholders can leverage innovative approaches to overcome the challenge of assessing and addressing contamination at these often large, complex mining sites. In the site assessment phase, identifying the type and extent of contamination is critical to a successful cleanup. Systematic project planning, dynamic work planning and the use of real-time measurement technologies under the Triad approach can facilitate efficient site characterization and are used to build a CSM. Technical considerations that can help develop a CSM that addresses the transport, mitigation and impacts of contamination for mining sites include:

- Type of mining site
- Past contamination and disposal practices
- Type and volumes of contaminated media
- Cleanup budget and time frame
- Current site topography
- Presence of mine shafts, openings or walls
- Intended end use of the site

Mining site remediation commonly involves often expensive conventional treatment technologies, including relocation of waste, clean soil cap, creating vertical wall barriers and water diversion tactics or detention basins. Innovative treatment technologies—including phytotechnologies, enhanced bioremediation, in situ chemical oxidation, permeable reactive barriers, and soil amendment application—can provide significant cost and time savings and other benefits.

An important aspect of mining site reclamation and redevelopment is the active participation by all stakeholders and decision makers. Upfront involvement by stakeholders and the community can help manage expectations and costly project changes that may arise after the cleanup begins. The development of a CSM under the Triad approach will insure that the stakeholders and community have the opportunity to review consistent data in the decision-making process.

Example Brownfields Mining Sites

- Suspected contamination at a former coal mine in Weirton, WV, obstructed redevelopment by prospective businesses. EPA awarded four Brownfield Assessment Grants to local councils and business groups to assess the former Weirton Steel property. After site assessments revealed no major contaminants were present, nearly $20 million was leveraged to complete redevelopment, leading to the creation of more than 350 jobs.
- After purchasing 16,500 acres in Luzerne County, PA, from the former Blue Coal Corporation, the local nonprofit Earth Conservancy mapped out a land use plan for the property. EPA supported the resulting cleanup efforts by awarding 12 Brownfield Cleanup Grants totaling $2.4 million. This seed money led to the reclamation of 2,000 acres of mine-scarred lands that will be developed into open recreational, residential and commercial spaces.

For More Information

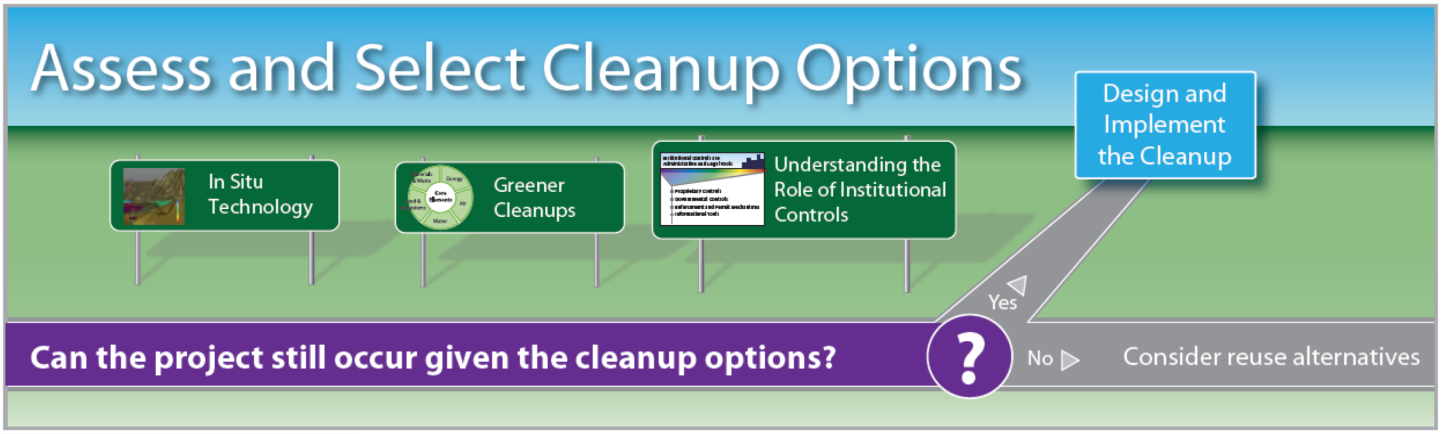
Information on ecological restoration opportunities such as wetland banks, is available at www.cluin.org/issues/default.focus/sec/characterization_cleanup_and_revitalization_of_mining_sites/cat/revitalization_and_reuse/. This website includes the report *Mine Site Cleanup for Brownfields Redevelopment: A Three-Part Primer*, which provides a detailed overview of cleanups at mining sites and offers innovative strategies, case studies and technical details on redevelopment. Additional information on mining site characterization, cleanup, and revitalization is available at www.clu-in.org/mining and www.epa.gov/superfund/abandoned-mine-lands-revitalization-and-reuse.

Federal Laws Related to Mining Site Remediation and Revitalization

Federal laws to be considered for mining site remediation and revitatlization include:

- Surface Mining Control and Reclamation Act (SMCRA)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- Clean Water Act (CWA)
- Resource Conservation and Recovery Act (RCRA)
- Toxic Substances Control Act (TSCA)
- Safe Drinking Water Act (SDWA)
- Clean Air Act (CAA)
- Treatment Approach Emergency Planning and Community Right-to-Know Act (EPCRA)
- National Environmental Policy Act (NEPA)

Visit www.epa.gov/laws-regulations/laws-and-executive-orders for an overview of these laws and further information.



The purpose of evaluating various cleanup alternatives is to identify technologies with the capability to meet specific cleanup and reuse objectives.

Evaluate Applicable Cleanup Alternatives for Your Site

Data collected during the site assessment and investigation phases are critical for moving to the cleanup phase of a Brownfields project. The project team and stakeholders use the data and information known about a property to review and evaluate remediation options applicable to specific site conditions and contaminants to achieve cleanup and reuse goals. Adequate planning and continuing to use the BMPs discussed in previous sections of this Road Map minimizes the need for additional data collection to support decisions regarding selection of cleanup options and ensures that stakeholders can contribute meaningfully to the decision-making process because they understand the site conditions and potential risks.

Sharing details about the cleanup options under consideration and inviting comment from those in the community likely to be affected by the redevelopment is important to the long-term community acceptance and support. Encouraging community involvement in these decisions helps to ensure that the approaches taken to address environmental impacts remain consistent with stakeholders' goals and objectives.

Identifying the Best Options for Challenging Cleanups

The cleanup of some Brownfields sites may be complicated by site conditions and the specific contamination found on or near the property. See Spotlight 9, Optimization Best Practices for Challenging Cleanups (next section), for a more detailed discussion.

Following community engagement activities, cleanup alternatives are identified. Factors to be considered and discussed among the project team for the Brownfield site cleanup alternatives include technologies with the capability to meet specific cleanup and redevelopment objectives, along with budget considerations and work schedule constraints that are important to having the project be financially viable.

Institutional controls (ICs)—to contain contamination in place or make it acceptably easier to limit exposure—are another important consideration during this phase. ICs include legal and administrative tools such as include easements, covenants, zoning restrictions and posting advisories to increase community awareness of the environmental conditions and cleanup activities at the site. See Spotlight 8, Understanding the Role of Institutional Controls at Brownfields Sites, for more information.

Selecting the Cleanup Options for Your Site

The following list identifies activities that are typically conducted during the evaluation and selection of cleanup options. The list is intended as a general planning guide and is not a comprehensive inventory of all activities to be undertaken during this phase. Factors to be considered are presented in the margins in the form of questions.

- Establish cleanup objectives and numeric goals that consider the likely end use. Use applicable standards, published state or federal guidelines, risk-based corrective actions (RBCA) or site-specific risk assessment results. It is essential that these objectives meet the specific statutory and regulatory requirements for the site and that the project team consider these objectives early in the process.
- Communicate information about the proposed cleanup option to Brownfields stakeholders. Solicit the input of the affected community in the site cleanup selection process and actively engage community members in decision making.
- Review general information about cleanup technologies and approaches to become familiar with those that may be applicable to the contaminants and geologic and hydrogeologic conditions present at the site. Focus on identifying cleanup options that have a proven track record for sites with similar contaminants and conditions:
  - See Appendix D (Guide to Contaminants and Technologies) for examples of technologies that are appropriate for specific types of contaminants.
  - Use the resources available www.epa.gov/remedytech to identify innovative cleanup technologies.
  - Search existing literature that further describes the technology alternatives.
  - Analyze detailed technical information about the applicability of technology alternatives.
- Enlist the help of a professional environmental practitioner with experience in applying these technologies at similar sites.
- Assess the need for using ICs as part of the remedy approach. At Brownfields sites the option to control risk by pathway restrictions is common.
- Narrow the list of potential cleanup options that are most appropriate and compatible for addressing site contamination and proposed reuse:
  - Network with other Brownfields stakeholders and environmental practitioners to leverage their expertise.
  - Determine whether sufficient data are available to support identification and evaluation of cleanup alternatives.

Consider These Questions

Goals and Planning

- Have site characterization uncertainties have been sufficiently reduced?
- What are the appropriate and feasible level of cleanup and how are they identified?

Oversight

- Are there federal, state, local or tribal cleanup requirements?
- Are there prescribed standards for the cleanup?
- Is there a state environmental insurance program?

The Community

- How can the community participate in the review and selection of options?
- What environmental standards should be considered to ensure that community stakeholders are satisfied with the outcome and process of the cleanup?
- Are cleanup options acceptable in light of community concerns?
- Are cleanup options compatible with regional or local planning goals and requirements?

Site Conditions

- Should risk-based approaches be considered for addressing exposure?
- Will the cleanup facilitate the planned redevelopment?
- Is there a need for ICs after cleanup? If so, will ICs facilitate or hinder development?

Consider These Questions

(continued)

Options

- Are the options acceptable in light of community concerns about protection and reuse of the site?
- What are the short- and long-term effects of the cleanup remedies under consideration?
- What options are available to monitor the performance of cleanup remedies?
- Are proposed ICs appropriate in light of community concerns?
- What plans, including financial assurances, are being made to ensure that ICs remain functional as long as contamination is present?
- Does the proposed cleanup approach place burdens on future land owners or occupants?

Timing and Funding

- How long will cleanup take?
- What will cleanup cost?
- Will schedule constraints or the estimated cost adversely affect the project's viability?
- Who will pay for long-term costs to maintain the remedy, including any ICs?

    - Analyze in more detail the applicability of technologies to the contamination and conditions identified at a site.
    - Determine whether combining remedies or technologies optimize cleanup at a site.
    - Evaluate the options against a number of key factors, including their effectiveness, implementability and cost.
    - Consider the benefits that some cleanup options may offer; for example, less disruption to the community, potential reduction of liability and long-term sustainability.
    - Determine the effects of various technology alternatives on redevelopment objectives.
- Continue to collaborate with regulatory agency stakeholders to ensure that regulatory requirements are properly addressed:
    - Confirm that the agencies concur that site characterization uncertainties have been sufficiently reduced to allow the process of remedy selection and design to begin.
    - Discuss or confirm cleanup objectives meet compliance with applicable statutory and regulatory requirements as well as requirements for intended use/reuse of the site.
    - Obtain agency input regarding the range of cleanup options under consideration and input regarding any additional options.
- Contact the EPA regional Brownfields coordinator to explore the potential for the project to qualify for a Brownfields cleanup grant, Revolving Loan Fund (RLF), or TBA support. Communities interested in applying for an EPA Brownfields cleanup grant should prepare an Analysis of Brownfields Cleanup Alternatives (ABCA), and an example of which is provided at www.epa.gov/sites/production/files/2015-10/documents/abca-example4cleanup-proposals.pdf.
- Integrate cleanup alternatives with reuse alternatives to identify potential constraints on reuse and time schedules and to assess cost and risk factors.
- Investigate environmental insurance policies, such as protection against cost overruns, undiscovered contamination and third-party litigation, and integrate their cost into the project financing strategy.
- Select an acceptable remedy that not only achieves cleanup goals and addresses the risk of contamination, but also best meets the objectives for redevelopment and reuse of the property and is compatible and sustainable with the needs of the community. Note, the cleanup approach may combine remedies.
- Build contingencies into the remedy and carefully develop matrices to monitor and determine progress toward meeting cleanup goals.

Find Helpful Resources

A wide variety of chemical contaminants may be present at Brownfields sites. Appendix D (Guide to Contaminants and Technologies) at the end of this document provides information about the applicability of technologies for particular types of Brownfields sites. Additional information on innovative cleanup technologies is available online at www.cluin.org/remediation/ and www.frtr.gov/scrntools.htm.

Plan Your Next Steps

After cleanup options have been selected for your site, consider the following options:

Result of the Review of Cleanup Options	Course of Action
The proposed cleanup option appears feasible.	Proceed to the Design and Implement the Cleanup phase.
No cleanup option appears feasible in light of the identified contamination or the proposed redevelopment and land reuse needs (such as project milestones, cost and intended reuse).	Determine whether revising the redevelopment plan remains a practicable option; if so, proceed to the Design and Implement Cleanup phase. Compliance with other programs, such as the EPA's RCRA and Superfund programs, may be required.

Spotlight 6

In Situ Technologies

The development of innovative treatment methods provides Brownfields stakeholders with new options for faster and more effective site cleanup. New approaches to site cleanup, based on the use of in situ, or in place, treatment technologies, promote more targeted or "surgical" options for cleanup by enabling a better understanding of subsurface features, contaminant distribution, volume, mass and behavior over time. Each technology has its limitations and suitable applications.

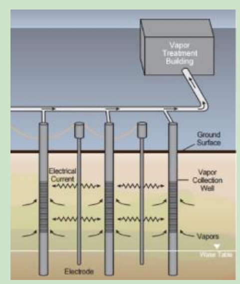
Benefits of In Situ Treatment

In situ treatment technologies are chemical, physical, biological, thermal or electrical processes that remove, degrade, chemically modify, stabilize or encapsulate contaminants within the soil or groundwater, in place. Methods that actively treat or destroy contaminants can reduce the time required to clean up a site, decrease the amount of residual contamination left at sites and minimize the need for long-term operations and maintenance. Together, these benefits can directly serve the interests of Brownfields stakeholders by:

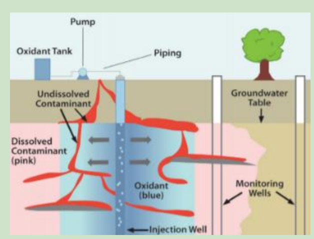
- Expediting site redevelopment and reuse.
- Reducing the requirement for engineering controls (EC) and institutional controls (ICs).
- Lowering or eliminating risks from long-term expenditures related to environmental protection measures.

In situ treatment remedies can also provide the added value of supporting the goals of greener cleanups. For example, in situ treatments can reduce the amount of treatment materials and waste generation and handling. In situ technologies or strategies can also be used to address residual contamination after more active and aggressive strategies are used to address the source.

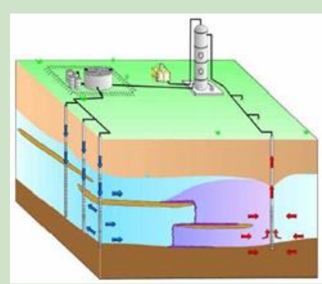
Examples of In Situ Technologies



- **In Situ Thermal (IST)** is the application of heat to contaminated soil and/or groundwater, causing the destruction or volatilization and mobilization of organic chemicals in the subsurface. As the chemicals volatilize into gases, they can be extracted via collection wells and treated in an ex situ treatment system at the surface. Heat can be introduced to the subsurface by electrical resistance heating, radio frequency heating, thermal conduction or injection of hot water, hot air or steam. IST is effective for remediation of dense or light nonaqueous phase liquids (DNAPLs or LNAPLs).



- **In Situ Chemical Oxidation (ISCO)** is a remediation technology that involves injecting chemical oxidants, such as permanganate, persulfate and hydrogen peroxide, into the contaminated groundwater and/or soil where contaminants are chemically converted into nonhazardous or less toxic compounds that are often more stable or inert. ISCO can be applied to a wide range of volatile and semivolatile hazardous contaminants, including DNAPLs and dissolved-phase chemicals emanating from the source zones.



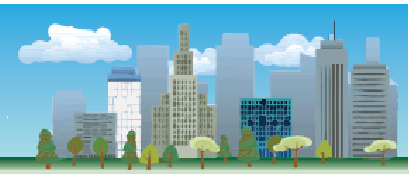
- **In Situ Flushing** involves flooding the contamination zone with an appropriate solution to remove the contaminant from the soil. The contaminants are mobilized by solubilization, emulsification or a chemical reaction as the solution is injected or infiltrated into the contaminated area. Then the contaminant-bearing fluid is collected and brought to the surface for disposal, recirculation or on-site treatment and reinjection. In situ flushing can be combined with other remedies, applied in both the vadose and saturated zones, and is applicable to a wide range of contaminants. In situ flushing is ineffective for dissolved-phase plumes and low permeability soils. Extensive laboratory testing is required to determine the most effective chemical solution.

For More Information

Information on in situ remediation technologies visit www.cluin.org/remediation and combined remedy resources at www.clu-in.org/products/combinedremedies/.

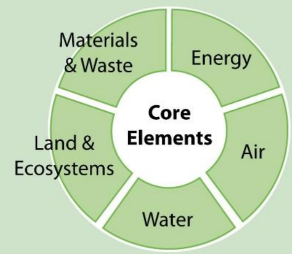
Spotlight 7

Greener Cleanup Practices



Cleanup actions, while protective of the environment, also have their own "environmental footprint"—they use energy, water and materials. To reduce this footprint, cleanups can be performed in a "greener" manner by considering the environmental effects of remedy implementation and incorporating options to minimize the impact of cleanup actions. Principles of greener cleanup can be applied throughout the site assessment and cleanup process. It can be advantageous to consider these options early to reduce the overall footprint of the project. Greener cleanup BMPs can reduce environmental impacts while maintaining cleanup objectives and ensuring that the remedy is protective of human health and the environment.

Core Elements of Greener Cleanups



- Reduce total *energy* use by improving energy efficiency and increasing use of energy from renewable resources.
- Reduce *air* emissions of greenhouse gases and criteria pollutants such as ozone, nitrogen dioxide and sulfur dioxide.
- Protect *water* resources and reduce water use.
- Reduce *waste* and improve *materials* management.
- Safeguard the *land and ecosystem* during site cleanup.

ASTM Standard E2893-16 "Standard Guide for Greener Cleanups" provides:

- A systematic protocol to identify, prioritize, select, implement and report on the use of BMPs to reduce the environmental footprint of cleanup activities.
- A list outlining 115 BMPs that are linked to the core elements of a greener cleanup and to relevant cleanup technologies.
- Guidelines to quantify the environmental footprint of cleanup activities.
- A reporting structure to promote public availability of information relating to the decision making process and communication of outcomes.

Examples of Sites Implementing Greener Cleanups

- The Whitney Young Branch Library Brownfields Site, in Chicago, IL, used the ASTM Standard Guide for Greener Cleanups to select BMPs for reducing the environmental footprint of the tetrachloroethene (PCE) site cleanup methods.
- The Grove Landfill Site in Austin, TX, utilized materials recycling, clean energy use and habitat restoration throughout the Brownfields cleanup of contaminated soil and surface water.

Mixing Trenches: *At the Whitney Young Branch Library Brownfields Site, chemical oxidation reagents were mixed in three 16- by 16-foot trenches reinforced by steel. After mixing was complete, the steel was removed and reused onsite for purposes such as sidewalk shoring.*

Footprint Assessment Tools

- The Green Remediation Focus Footprint Assessment website provides a summary of available tools to evaluate the environmental footprint of remediation processes (www.cluin.org/greenremediation/footprintassessment).

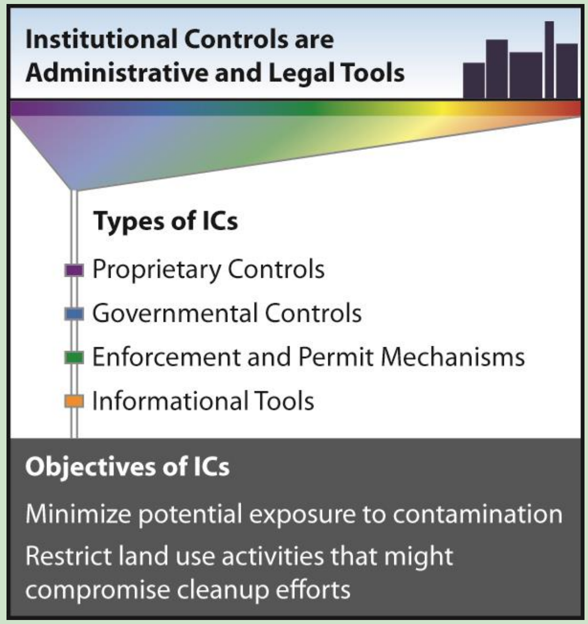
For More Information

The Green Remediation Focus page of the EPA's CLU-IN website at www.cluin.org/greenremediation provides information on integrating green remediation and BMPs into cleanups and case studies that describe green remediation implementation. More information on the ASTM Standard Guide for Greener Cleanup is available at www.epa.gov/greenercleanups/greener-cleanup-consensus-standard-initiative.

Spotlight 8

Understanding the Role of Institutional Controls at Brownfield Sites

ICs are a broad spectrum of administrative and legal tools used to help minimize the potential for exposure to residual contamination and to protect physical cleanup measures at contaminated sites. ICs work by limiting land or resource use or by providing information that helps modify or guide human behavior at a site. ICs typically supplement engineering controls and are used in conjunction with the overall cleanup remedy to support reuse. Long-term considerations associated with IC use, such as impacts on reuse and funding requirements, should be carefully weighed against the costs and benefits of permanent removal of contamination.



Types of ICs

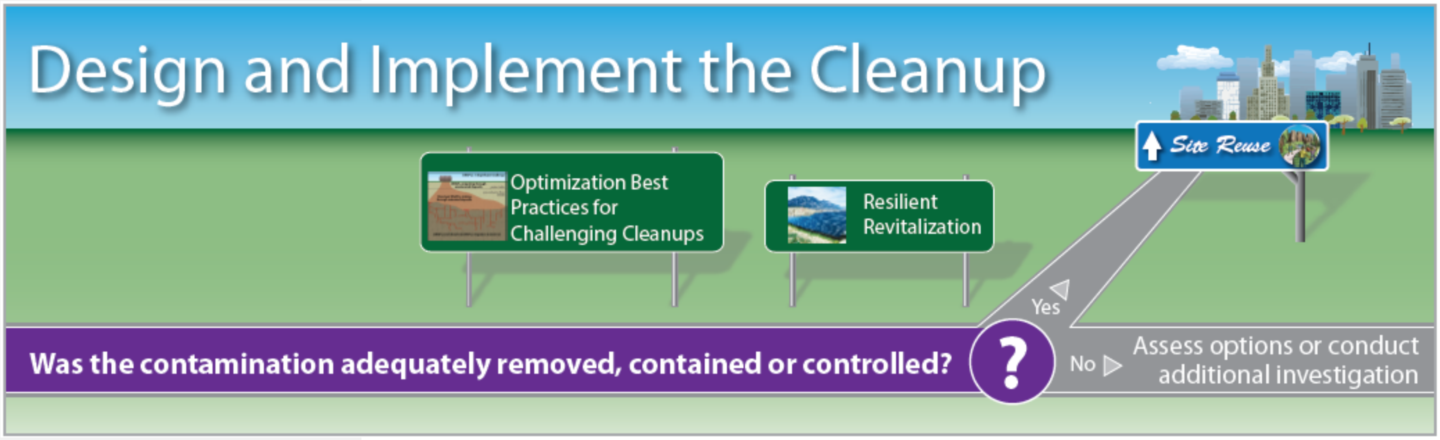
- *Proprietary controls* involve private agreements that impose restrictions on, or otherwise affect the use of, a property. Common examples of proprietary controls are covenants, deed restrictions and easements.
- *Governmental controls*, such as zoning, building codes, groundwater use regulations and commercial fishing bans, restrict land or resource use by the authority of a government entity.
- *Enforcement and permit tools with IC components* typically involve administrative orders, consent decrees and permits to limit certain activities at a site or require a specific activity, such as monitoring and reporting.
- *Informational devices*, such as signs, markers and community outreach activities, provide notification and may communicate risks about residual contamination that may remain on a site after a cleanup remedy has been undertaken.

Long-Term Considerations

- Identify the long-term costs and administrative implications of maintaining and enforcing ICs.
- Evaluate the potential use of ICs early in the cleanup process to plan appropriately for implementation, maintenance and enforcement challenges.
- Consider and compare leaving contamination in place while maintaining ICs to treating or removing contamination, including costs, risks, site reuse and other factors.

For More Information

The EPA's guidance *Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites* highlights some of the common issues that may be encountered when working with ICs, and provides an overview of EPA's policy regarding the roles and responsibilities of the parties involved in the various life-cycle stages of ICs. This document is available online at www.epa.gov/fedfac/institutional-controls-guide-planning-implementing-maintaining-and-enforcing-institutional. In 2009, the EPA released the fact sheet *An Introduction to the Cost of Engineering and Institutional Controls at Brownfield Properties*, which provides general information about the costs of ECs and ICs at Brownfields sites and includes an example of the use of ICs as part of a site cleanup, and is available online at www.epa.gov/sites/production/files/2015-09/documents/lts_cost_fs.pdf. A 2017 EPA document *Long Term Stewardship at Leaking Underground Storage Tank Sites with Residual Contamination* provides an overview and approaches to long-term stewardship as well as tips and resources for achieving long-term stewardship at leaking underground storage tanks (UST) sites. The document is available online at www.epa.gov/ust/long-term-stewardship-leaking-underground-storage-tank-sites-residual-contamination.



The final phase of preparing a Brownfields property for reuse is designing and implementing the cleanup. During this phase, the discovery of additional contamination may require further site investigation or reassessment of available cleanup options.

Maintaining stakeholder participation during cleanup promotes long-term community acceptance and support of the planned reuse of the Brownfields site.

Develop and Carry Out Your Detailed Cleanup Plans

During the cleanup design and implementation phase, the property is prepared for redevelopment and reuse by carrying out the selected cleanup approach. The design of a cleanup plan and implementation of the chosen remedies involves close coordination with all other redevelopment efforts in the immediate vicinity of the site.

Building on the comprehensive understanding of site conditions that has evolved during the project, real-time technologies and dynamic work strategies can be used to monitor and assess the results of cleanup activities. As in the site investigation phase, these field-based methods can be used to evaluate progress toward the achievement of the cleanup goals. Accurate monitoring data help to minimize uncertainty and form the basis for long-term monitoring strategies, including the use of ICs.

In some cases, implementing the cleanup may lead to the discovery of additional contamination or may reveal other complicating factors that require the project team to conduct further site investigation and characterization. Additional site investigation results may demonstrate that no practical alternatives exist for cleaning up the site to meet the reuse goals of the project; if so, the site owner may need to consider modifying the proposed land reuse plan or identifying other land use alternatives. See Spotlight 9, Optimization Best Practices for Challenging Cleanups, for details about sites affected by contaminants that are difficult to investigate and clean up.

Design and Implement Your Cleanup

Typical activities that may be conducted during this phase are outlined below, along with factors to consider. The list is intended as a general planning guide and is not a comprehensive inventory of all activities to be undertaken during cleanup of a Brownfields site.

- Review all applicable federal, state, local and tribal regulations and regulatory guidelines to identify specific requirements, including guidelines for state VCPs. Keep in mind that new regulations can become effective in the middle of the project.
- Continue to engage regulatory stakeholders to ensure that regulatory requirements are being properly addressed:
    - Confirm that the agency has reviewed the cleanup plan and concurs with the design of the selected remedy.
    - Obtain agency input and concurrence on remedy assessment metrics and alternative exit strategies.
    - Upon completion of remediation activities, consult with regulatory stakeholders on the process of receiving a decision of "no further action." Each state program has specialized conditions and requirements for the certification and delisting process. More information is available online at www.epa.gov/brownfields/cleaning-brownfields-under-state-response-programs-getting-no-further-action.
- Contact the state Brownfields program and the EPA regional Brownfields coordinator to identify and determine the availability of state and EPA support programs.
- Develop cleanup and subsequent monitoring plans that incorporate technology options and consider the effect of any cleanup activities on the proposed reuse of the property and the schedule for project design or construction:
    - Develop or review the schedule for completion of the project.
    - Obtain a final amount for the grant funding available for project development.
    - Consider duration and clear endpoints of the remedial action which directly impacts the reuse schedule and costs.
    - Coordinate renovation and construction of infrastructure with cleanup activities.
    - Coordinate activities with developers, financiers, construction firms and members of the local community.
- Establish contingency plans to address the discovery of additional contamination during cleanup, including tools such as environmental insurance policies, or to supplement or replace the initial approach if progress towards achieving cleanup objectives is not satisfactory.
- Continue to maintain stakeholder consensus and active community participation during cleanup:
    - Conduct public outreach meetings on a regular basis.
    - Provide updates about the progress of cleanup activity.
    - Share successes when important cleanup milestones are achieved.
    - Inform the community about changes in activity that could affect reuse plans.

Consider These Questions

Goals and Planning

- How will the cleanup be monitored and assessed?
- Does the projected length of time required for cleanup take into account contingencies or long-term monitoring?
- Have alternative land use strategies been developed?

Oversight

- Are there federal, state, local and tribal requirements for the design, installation and monitoring of cleanup activities?

The Community

- How will the community participate in this phase?
- Are there examples of effective community engagement?

Site Specifics

- Can redevelopment and cleanup activities be performed concurrently?
- Will ICs facilitate or hinder redevelopment in the future?

Options

- How will the cleanup design affect long-term liabilities or future use of the site?
- What can be done to protect the community and other property during cleanup?

Funding

- What are the tradeoffs between cost and meeting project deadlines?
- How will long-term monitoring be funded and managed?

- Implement, document and monitor the performance of the cleanup using the accepted assessment metrics.
- Work with the state VCP, if applicable, and with tribal, county or local officials to facilitate the placement and implementation of ICs.

Plan Your Next Steps

After the cleanup is completed, consider the following courses of action:

Result of Cleanup	Course of Action
Contamination has been adequately removed, contained or controlled.	Before proceeding with redevelopment activities, consult with the appropriate regulatory officials to receive a “no further action” decision.
Additional contamination has been discovered.	Consult with appropriate regulatory officials to determine how to proceed with cleanup activities. You may need to return to the Investigate a Site phase to conduct additional sampling to delineate the extent and nature of the contamination and assess the impact of additional characterization and cleanup costs on the overall viability of the project.
Long-term site monitoring and operation and maintenance (O&M) of the site remedy is required.	Return to the Investigate a Site phase to evaluate options, including cost considerations, for long-term monitoring and O&M, and as necessary collect after-performance samples for monitoring cleanup. Coordinating redevelopment and cleanup may mean future users take on roles associated with some aspects of maintenance, such as mowing or asphalt repair.

Next Step: Revitalization!

The Road Map provides valuable information to help Brownfields stakeholders better understand and implement the steps for investigating and cleaning up Brownfields sites. It also increases their awareness and knowledge of the wide range of technologies and resources available to support these activities – all leading up to reuse of the Brownfields site. The next step, to merge onto the road to site revitalization and reuse, is the most rewarding because this is the realization and achievement of those goals defined at the beginning of the project. Now that the cleanup is complete, site redevelopment and revitalization can begin. It is time to review the reuse goals set at the start of the Road Map during the planning phase and discussed in Section 3: Learn the Basics. The reuse goals considered the interests of many stakeholders. Re-engaging those stakeholders, as well as any new stakeholders involved during the cleanup process, to review and update the goals, will help ensure site reuse serves the broadest interests in the community, including providing the economic and social benefits that come with a well-planned, well-designed, sustainable and resilient Brownfields site redevelopment.

Spotlight 9

Optimization Best Practices for Challenging Cleanups

Challenging Cleanups at Brownfields Sites

Brownfields sites contaminated with chemicals that are highly mobile, not easily accessible (for example, located in fractured bedrock) or difficult to treat can lead to challenging investigations and cleanups.

Contaminants associated with challenging cleanups include dense nonaqueous phase liquids (DNAPLs), polychlorinated biphenyls (PCBs), dioxins/furans, 1,4-dioxane, methyl tertiary butyl ether (MTBE), perchlorate and arsenic. Such contamination may be found at former gas stations, electronics manufacturing facilities, auto service centers, dry cleaning facilities, electroplating plants, wood preservation sites and manufactured gas plants.

A Closer Look at DNAPLs

Two factors make DNAPLs a contaminant that is difficult to clean up: (1) they do not easily dissolve in water and (2) they are denser than water. Being denser than water, DNAPLs tend to sink through groundwater and permeate into fine-grained soil units, and can act as continuous sources of contamination. Used alone, traditional pump-and-treat systems may require years to decades to clean up groundwater contaminated with DNAPLs. In these cases, it is important to consider more effective, innovative alternatives. Examples of such treatments include:

- Using microorganisms to break down the contamination (enhanced bioremediation).
- Extracting DNAPL compounds from soil in vapor form with a vacuum system and treating the gas to remove the contaminants (soil vapor extraction [SVE]).
- Applying chemicals to the contamination to break down the DNAPLs into nonhazardous compounds such as water and carbon dioxide (in situ chemical oxidation injection).

Under certain conditions, the best solution may not involve treating the DNAPL; instead, the approach would be to define the extent of contamination and identify land use restrictions. This may involve making a determination that the remediation is not technically feasible or unable to meet cleanup objectives.

Best Practices for Optimization

Remediation optimization is the systematic site review by a team of independent technical experts, at any phase of site investigation and cleanup, to identify and implement specific actions that improve the effectiveness and efficiency with which an environmental remedy reaches its stated goals. For challenging cleanups, optimization can be used periodically to evaluate the cleanup, including system efficiency and progress towards cleanup goals. Best practices for optimization include:

- *Implementation of comprehensive, up-front planning* using site characterization methods such as systematic planning, real-time measurement technologies and dynamic work strategies.
- *Use of strategic sampling approaches* such as high resolution site characterization, incremental composite sampling and other approaches that accurately characterize contaminant levels and locations to help improve the technical understanding of site conditions as well as remedies.
- *Identification of the design parameters in support of the process selection decisions*, which can lead to better decisions as site conditions change or more information becomes available.
- *Augment data management* including data management planning, acquisition, processing, analysis, preservation and storage and publication and sharing.
- *Implementation of combined remedies* including concurrent combinations of technologies for different portions of contaminated media and multiple technologies to address contamination at different points in time.
- *Implementation of a more targeted approach* that applies technologies to a specific and well-defined area.
- *Streamline monitoring* by adjusting monitoring frequency, monitoring locations, chemical of concern analyzed as well as analysis of monitoring results over time.
- *Implementation of greener cleanups* by incorporating options to minimize the environmental footprint of characterizing and cleaning up sites.

Benefits of optimization include improvements in CSM, data management, remedies and monitoring as well as increasing remedy effectiveness, improving technical performance, reducing costs and expediting site closure.

For More Information on challenging cleanups visit www.cluin.org/contaminantfocus. Resources on Optimization Best Practices are available at www.epa.gov/superfund/cleanup-optimization-superfund-sites and www.cluin.org/optimization/.

Spotlight 10

Resilient Revitalization

Incorporating resilient revitalization into Brownfields assessments and cleanups helps to protect human health and the environment now and into the future. Resilient revitalization adaptations are adjustments that societies or ecosystems make to limit the negative impacts of weather-related changes or to prepare for and adjust to future weather-related impacts. By considering resilient revitalization during the planning process and assessment phase, stakeholders can identify weather-related factors prior to Brownfields redevelopment and associated mitigation measures to help ensure that cleanups remain effective as the weather changes. For example, stakeholders can consider how changing temperature and precipitation patterns may impact the toxicity, fate and transport of onsite contaminants of concern and develop a plan that addresses these changes.

As discussed in the *Climate Smart Brownfields Manual,* stakeholders can consider observed and predicted weather-related changes in the project area as well as site-specific risk factors. Examples include:

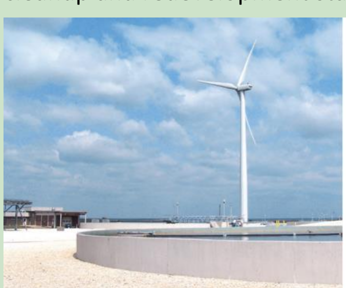
- Increased/decreased temperatures.
- Increased/decreased precipitation.
- Extreme weather events (e.g., storms of unusual intensity, increased frequency and intensity of localized flooding events).
- Increased risk of wildfires.
- Changing dates for ground thaw/freezing.
- Rising sea level.
- Changing flood zones.
- Changing environmental/ecological zones.
- Increased salt water intrusion.
- Higher/lower groundwater tables.

Stakeholders should consult authoritative resources such as the U.S. Geological Survey or National Weather Service to identify weather-related changes that might impact the site, accounting for site-specific risk factors such as proximity to tidal waterways, property affected by a revised Federal Emergency Management Agency (FEMA) flood plain map or site vulnerabilities due to changing hydraulic conditions. Although the ABCA should include an evaluation of how well each alternative can accommodate risk factors associated with weather-related changes, EPA does not expect stakeholders to generate new site-specific weather-related data. In the ABCA, grant recipients should demonstrate that they reviewed all relevant available data. The level of analysis expected depends on site complexity and risk associated with the remedial options and site redevelopment goals.

A good time to start incorporating resilient revitalization in a Brownfields project is during the Phase I ESA. The evaluation of historic site information can be expanded to include historic and more recent weather patterns. Consider weather-related vulnerabilities and resiliency of site structures, soil, vegetation and other elements in the site area. After the site assessment phase, Brownfields redevelopment can also incorporate weather-related change mitigation. Stakeholders should consider the environmental footprint of all site activities by exploring and implementing green remediation strategies to maximize sustainability, reducing energy and water usage, promoting carbon neutrality, promoting materials reuse and recycling, increasing urban greenspace and preserving land resources through green applications. These efforts can help ensure that, along with weather-related change adaptation, resilient revitalization is incorporated in the Brownfields redevelopment process.

For More Information

EPA's *Climate Smart Brownfields Manual* offers detailed tools, strategies and case studies that can assist in the Brownfields cleanup and redevelopment stages, and is available at www.epa.gov/land-revitalization/climate-smart-brownfields-manual.




Appendix A

CSM and General Cleanup Steps: Crosswalk of Regulatory Program Stages and CSM Life Cycle Phases

General Environmental Cleanup Steps	CSM Life Cycle	Best Management Practices		CERCLA - Superfund	RCRA	Brownfields	UST	VCUP Varies by state
		SPP	DWS/ RTMT					
Site Assessment	Conceptual **Preliminary CSM** **Baseline CSM**			Preliminary Assessment (PA) Site Inspection (SI) National Priorities List (NPL) No Further Remedial Action Planned (NFRAP)	Facility Assessment (RFA)	Phase I Environmental Site Assessment (ESA)	Initial Site Characterization Initial Response	PA SI
Site Investigation and Alternatives Evaluation	**Characterization CSM Stage**			Remedial Investigation/ Feasibility Study (RI/FS) Removal Actions - Emergency/Time Critical/Non-Time-Critical	Facility Investigation (RFI) Corrective Measures Study (CMS)	Phase II ESA	SI Corrective Action Plan (CAP)	RI/FS
Remedy Selection	**Design CSM Stage**			Proposed Plan Record of Decision (ROD)	Statement of Basis (SB) Final Decision and Response to Comments	Remedial Action Plan (RAP)	Cleanup Selection	ROD
Remedy Implementation	**Remediation/Mitigation CSM Stage**			Remedial Design (RD) Remedial Action (RA) – Interim and Final	Corrective Measure Implementation (CMI)	Cleanup and Development	Corrective Action - Low-impact site cleanup - Risk-based remediation - Generic remedies - Soil matrix cleanup	RD RA
Post-Construction Activities	**Post-Remedy CSM Stage**			Operational & Functional Period Operation & Maintenance (O&M) Long term monitoring (LTM) Optimization Long Term Response Action (Fund-lead groundwater/surface water restoration)	O&M On-site inspections and oversight	Property Management Long-term O&M Redevelopment Activities (Private- and Public-led)	LTM	O&M LTM
Site Completion	Quantitative			Construction Complete (CC) Preliminary or Final Close Out Report (PCOR/FCOR) Site Completion - FCOR Site Deletion O&M as appropriate	Certification of Completion Corrective Action Complete with Controls or without Controls	CC Property Management	No Further Action (NFA)	CC

Abbreviations presented in the title row:

CSM = Conceptual Site Model
SPP = Systematic Project Planning
DWS = Dynamic Work Strategies
RTMT = Real Time Measurement Technologies

CERCLA = Comprehensive Environmental Response, Compensation and Liability Act

RCRA = Resource Conservation and Recovery Act
UST = Underground Storage Tanks
VCUP = Voluntarily Clean Up Programs

The Road Map outlines a general cleanup process and the names of the steps in this process are specific to the cleanup of Brownfields sites. The matrix above, *CSM and General Cleanup Steps: Crosswalk of Regulatory Program Stages and CSM Life Cycle Phases*, is a crosswalk of the various terminology and steps of different cleanup programs, illustrating that the general cleanup process applies to all these programs.

Use of terminology from regulatory frameworks is not intended to supplement any specific programmatic requirements or guidance. However, irrespective of the environmental program driving site cleanup, use of the components of a CSM in a flexible and comprehensive framework can facilitate site decision making throughout the site-cleanup process. Additionally, the use of SPP and a dynamic CSM along with DWS and RTMT at each key project stage can improve project efficiency and effectiveness.

Note: The width and gradation of the blue arrows demonstrating BMPs indicate the relative level of effort applied and the resulting impact and value of performing the BMPs at the indicated project stages.

Appendix B
LIST OF ACRONYMS

AA	Atomic Absorption
ABCA	Analysis of Brownfield Cleanup Alternatives
AES	Atomic Emission Spectroscopy
AML	Abandoned Mine Land
ARC	Assessment, Revolving Loan Fund and Cleanup
ASV	Anodic Stripping Voltammetry
ASTSWMO	Association of State and Territorial Solid Waste Management Officials
AWP	Area-Wide Planning
BMP	Best Management Practice
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
CCA	Chrome-copper Arsenate
CC	Construction Complete
CCl4	Carbon Tetrachloride
CDFA	Council of Development Finance Agencies
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CEI	Community Engagement Initiative
CLU-IN	Contaminated Site Clean-up Information
CMI	Corrective Measure Implementation
COC	Contaminant of Concern
CSM	Conceptual Site Model
CWA	Clean Water Act
DIAL	Differential Adsorption LIDAR
DNAPL	Dense Nonaqueous Phase Liquid
DO	Dissolved Oxygen
DPT	Direct-Push Technology
DQO	Data Quality Objective
DWS	Dynamic Work Strategy
EC	Engineering Control
ECD	Electron Capture Detector
EISB	Enhanced In Situ Bioremediation
EOU	Excessive, Obsolete, or Unserviceable Munitions
EPA	U.S. Environmental Protection Agency
ERH	Electrical Resistive Heating
ESA	Environmental Site Assessment
EWDJT	Environmental Workforce Development and Job Training
FDIC	Federal Deposit Insurance Corporation
FFD	Fuel Fluorescence Detector
FID	Flame-Ionization Detector
FOCS	Fiber Optic Chemical Sensors
FPXRF	Field-Portable X-Ray Fluorescence
FSP	Field Sampling Plan
FY	Fiscal Year
GC	Gas Chromatography
GC/MS	Gas Chromatography/Mass Spectrometry
GIS	Geographic Information Systems
GPR	Ground Penetrating Radar
GPS	Global Positioning System
HPT	Hydraulic Profiling Tool
HRSC	High-Resolution Site Characterization
IA	Immunoassay
IC	Institutional Control
IMS	Ion Mobility Spectrometry
ISB	In Situ Bioremediation
ISCO	In Situ Chemical Oxidation
ISM	Incremental Sampling Method
ISO	In Situ Oxidation
IST	In Situ Thermal
ITRC	Interstate Technology and Regulatory Council
KSU	Kansas State University
LEL	Lower Explosive Limit
LIDAR	Light Detection and Ranging
LIF	Laser-Induced Fluorescence
LNAPL	Light Nonaqueous Phase Liquid
LTM	Long-Term Monitoring
LUST	Leaking Underground Storage Tank
MIP	Membrane Interface Probe
MS	Mass Spectrometer
MSL	Mine-Scarred Land
MTEL	Methyl Tetraethyl Lead
NAPL	Nonaqueous Phase Liquid
NFA	No Further Action

NFRAP No Further Remedial Action Planned
NPDES National Pollutant Discharge Elimination System
NPL National Priorities List
OB Open Burn
OD Open Detonation
OLEM Office of Land and Emergency Management
O&M Operation and Maintenance
OSRE Office of Site Remediation Enforcement
OSRTI Office of Superfund Remediation and Technology Innovation
OUST Office of Underground Storage Tanks
P&T Pump and Treat
PAH Polycyclic Aromatic Hydrocarbon
PA/SI Preliminary Assessment/Site Investigation
PCB Polychlorinated Biphenyl
PCE Tetrachloroethene
PCOR/FCOR Preliminary or Final Close Out Report
PCP Pentachlorophenol
PID Photo Ionization Detector
PRB Permeable Reactive Barrier
PRP Potentially Responsible Party
QAPP Quality Assurance Project Plan
RBCA Risk-Based Corrective Action
RCRA Resource Conservation and Recovery Act
RD/RA Remedial Design/Remedial Action
REC Recognized Environmental Condition
REDOX Reduction/Oxidation
RFA RCRA Facility Assessment
RFI RCRA Facility Investigation
RI/FS Remedial Investigation/Feasibility Study
RFH Radio Frequency Heating
FP Request for Proposal
RLF Revolving Loan Fund
ROD Record of Decision
ROST Rapid Optical Screening Tool
RTMT Real Time Management Technologies
S/S Solidification/Stabilization
SB Statement of Basis
SC Specific Conductance
SEMS Superfund Enterprise Management System
SERS Surface-Enhanced Raman Scatter
SMCRA Surface Mining Control and Reclamation Act
SPP Systematic Project Planning
SRI Superfund Redevelopment Initiative
SVE Soil Vapor Extraction
SVOC Semivolatile Organic Compound
TAB Technical Assistance to Brownfields
TBA Targeted Brownfields Assessments
TCE Trichloroethene or Trichloroethylene
TEL Tetraethyl Lead
TSCA Toxic Substances Control Act
USGS U.S. Geological Survey
UST Underground Storage Tank
UV Ultraviolet
UVF Ultraviolet Fluorescence
VCP Voluntary Cleanup Program
VI Vapor Intrusion
VOC Volatile Organic Compound
XRF X-Ray Fluorescence
XSD Halogen Specific Detector

Appendix C

References and Additional Information

This appendix lists the sources of information referenced in this document and associated links, where available, along with webpages that contain additional information related to the Brownfields Road Map.

References

ATSM International. 2015. Standard Guide for Vapor Encroachment Screening on Property Involved in Real Estate Transactions. ASTM E2600-15. https://www.astm.org/Standards/E2600.htm

ATSM International. 2011. Standard Practice for Environmental Site Assessments: Phase II Environmental Site Assessment Process. ASTM E1903-11. https://www.astm.org/Standards/E1903.htm

ATSM International. 2013. Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process. ASTM E1527-13. https://www.astm.org/Standards/E1527.htm

U.S. Environmental Protection Agency (EPA). 2005. Mine Site Cleanup for Brownfields Redevelopment: A Three-Part Primer. Office of Solid Waste and Emergency Response (OSWER). EPA 542-R-05-030. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1007S4F.PDF?Dockey=P1007S4F.PDF

EPA. 2008. Addressing Long Term Stewardship: Highlights from the Field. Office of Solid Waste and Emergency Response (OSWER). https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1003UTU.txt

EPA. 2009. An Introduction to the Cost of Engineering and Institutional Controls at Brownfield Properties. February. Office of Solid Waste and Emergency Response (OSWER). EPA-560-F-08-244. https://www.epa.gov/sites/production/files/2015-09/documents/lts_cost_fs.pdf

EPA. 2012a. Brownfields ABCA Example for Cleanup Grant Proposals. https://www.epa.gov/sites/production/files/2015-01/documents/abca_example_for_cleanup_proposals.pdf

EPA. 2012b. Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites. December. Office of Solid Waste and Emergency Response (OSWER). OSWER 9355.0-89 EPA-540-R-09-001. https://www.epa.gov/sites/production/files/documents/final_pime_guidance_december_2012.pdf

EPA. 2013. Formative Evaluation of the OSWER Community Engagement Initiative. October. Office of Policy. EPA-100-K-15-001. https://www.epa.gov/sites/production/files/2015-10/documents/ce-eval-report-final.pdf

EPA. 2014a. 2014 State Brownfields and Voluntary Response Programs. December. Office of Solid Waste and Emergency Response (OSWER). EPA-42-F-14-215. https://www.epa.gov/sites/production/files/2015-11/documents/brownfields_state_report_2014_508_12-17-14_final_web.pdf

EPA. 2014b. The Revitalization Handbook - Revitalizing Contaminated Lands: Addressing Liability Concerns. June. Office of Site Remediation Enforcement, Office of Enforcement and Compliance Assurance. https://www.epa.gov/sites/production/files/2014-06/documents/revitalization-handbook-2014-cleanup-enforcement.pdf

EPA. 2015a. Brownfields Success Story: Reclaiming Abandoned Mine Lands Once Parcel at a Time – Luzerne County, Pennsylvania. August. EPA 560-15-197. https://www.epa.gov/sites/production/files/2015-10/documents/epa_oblr_successstory_earth_conservancy_v4_508.pdf

EPA. 2015b. EPA's Vapor Intrusion Guide. October. Office of Solid Waste and Emergency Response (OSWER). https://www.epa.gov/sites/production/files/2016-10/documents/factsheet.pdf

EPA. 2015c. OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air. June. Office of Solid Waste and Emergency Response (OSWER). OSWER Publication 9200.2-154. https://www.epa.gov/sites/production/files/2015-09/documents/oswer-vapor-intrusion-technical-guide-final.pdf

EPA. 2016a. Brownfields Stakeholder Forum Kit. August. Office of Land and Emergency Management (OLEM). EPA 560-K-16-003. https://www.epa.gov/sites/production/files/2016-09/documents/final_final_stakeholder_forum_toolkit_8.25.2016.pdf

EPA. 2016b. Cleaning Up Brownfields under State Response Programs – Getting to 'No Further Action'. August. Office of Land and Emergency Management (OLEM). EPA 560-K-16-002. https://www.epa.gov/sites/production/files/2016-08/documents/final_nfa_document_layout_8-1-16.pdf

EPA. 2016c. Climate Smart Brownfields Manual. December. Office of Land and Emergency Management (OLEM). EPA 560-F-16-005. https://www.epa.gov/sites/production/files/2017-01/documents/final_climate_smart_brownfields_manual_online_version.pdf

EPA. 2016d. Errata for OSWER Technical Guide For Assessing And Mitigating The Vapor Intrusion Pathway From Subsurface Vapor Sources To Indoor Air. September. OSWER Publication 9200.2-154. https://www.epa.gov/sites/production/files/2016-10/documents/errata.pdf

EPA. 2016e. Setting the Stage for Leveraging Resources for Brownfields Revitalization. April. Office of Land and Emergency Management (OLEM). EPA 560-K-16-001. https://www.epa.gov/sites/production/files/2016-04/documents/final_leveraging_guide_document_4-19-16.pdf

EPA. 2017. Brownfields Success Story: A Former Coal Mine Springs to Life – Weirton, West Virginia. October. EPA 560-17-222. https://www.epa.gov/sites/production/files/2017-10/documents/epa_oblr_successstory_three_springs_business_park.pdf

Additional Information

EPA. ANNOUNCING New Request for Proposals - FY 2018 Brownfields Assessment, Revolving Loan Fund, and Cleanup Grant Guidelines. https://www.epa.gov/brownfields/announcing-new-request-proposals-fy-2018-brownfields-assessment-revolving-loan-fund-and

EPA. Brownfields All Appropriate Inquiries. https://www.epa.gov/brownfields/brownfields-all-appropriate-inquiries

EPA. Brownfields State and Tribal Program Updates. https://www.epa.gov/brownfields/brownfields-state-tribal-program-updates

EPA. Brownfields Technical Assistance and Research. https://www.epa.gov/brownfields/brownfields-technical-assistance-and-research

EPA. Cleanup and Optimization at Superfund Sites. https://www.epa.gov/superfund/cleanup-optimization-superfund-sites

EPA. Cleanups At Federal Facilitates: Community Engagement. https://www.epa.gov/fedfac/community-engagement

EPA. CLU-IN. Containment Focus: Introduction. https://clu-in.org/contaminantfocus/

EPA. CLU-IN. Green Remediation Focus. https://clu-in.org/greenremediation/

EPA. CLU-IN. Green Remediation Focus: Footprint Assessment. https://clu-in.org/greenremediation/footprintassessment

EPA. CLU-IN. Optimizing Site Cleanups. https://clu-in.org/optimization/

EPA. CLU-IN. Technologies: Remediation. https://clu-in.org/remediation/

EPA. CLU-IN. Vapor Intrusion. https://clu-in.org/issues/default.focus/sec/Vapor_Intrusion/cat/Overview/

EPA. Community Engagement and the Underground Storage Tank Program. https://www.epa.gov/ust/community-engagement-and-underground-storage-tank-program

EPA. Council of Development Finance Agencies. CDFA Brownfields Technical Assistance Program. https://www.cdfa.net/cdfa/cdfaweb.nsf/0/AE4DCA6EF6C10A3788257D7000567D43

EPA. Federal Remediation Technologies Roundtable. Technology Screening Matrix. https://frtr.gov/scrntools.htm

EPA. Greener Cleanup Consensus Standard Initiative. https://www.epa.gov/greenercleanups/greener-cleanup-consensus-standard-initiative

EPA. Interstate Technology and Regulatory Council. Incremental Sampling Methodology. http://www.itrcweb.org/Team/Public?teamID=11

EPA. Interstate Technology and Regulatory Council. Sampling, Characterization, and Monitoring. http://www.itrcweb.org/Team/Public?teamID=45

EPA. Key Grant Resources for Applicants and Recipients. https://www.epa.gov/grants/key-grant-resources-applicants-and-recipients

EPA. Land Revitalization. https://www.epa.gov/land-revitalization

EPA. Petroleum Brownfields Action Plans. https://www.epa.gov/ust/petroleum-brownfields-action-plans

EPA. Petroleum Brownfields. https://www.epa.gov/ust/petroleum-brownfields

EPA. RE-Powering America's Land. https://www.epa.gov/re-powering

EPA. Revitalization Tools for Communities. https://www.epa.gov/land-revitalization/revitalization-tools-communities

EPA. Smart Growth. https://www.epa.gov/smartgrowth

EPA. State and Tribal Programs and Resources. https://www.epa.gov/brownfields/state-and-tribal-programs-and-resources

EPA. Superfund Cleanup Policies and Guidance. https://cfpub.epa.gov/compliance/resources/policies/cleanup/superfund/

EPA. Superfund Redevelopment Initiative. https://www.epa.gov/superfund-redevelopment-initiative

EPA. Triad Resource Center. https://triadcentral.clu-in.org/

EPA. Triad Resource Center Regulatory Information. https://triadcentral.clu-in.org/reg/

EPA. Types of Brownfields Grant Funding. https://www.epa.gov/brownfields/types-brownfields-grant-funding

EPA. Types of Brownfields Grant Funding, Types of Competitive Grant Funding. https://www.epa.gov/brownfields/types-brownfields-grant-funding

EPA. Vapor Intrusion. https://www.epa.gov/vaporintrusion

Appendix D

GUIDE TO CONTAMINANTS AND TECHNOLOGIES

This appendix is intended to help Brownfields stakeholders better understand the types of contaminants typically found at Brownfields sites by common site type and the range of technologies that may be appropriate for assessing and remediating those contaminants during the various phases of a site cleanup. Information is presented in Tables D-1 to D-3 as follows:

1. Table D-1 lists common site types and contaminant groups typically associated with the site types followed by short descriptions of each site type.

2. Table D-2 lists technologies that may be used to analyze contaminants typically found at Brownfields sites followed by short descriptions of each investigation technology.

3. Table D-3 lists technologies used to treat contaminant groups typically found at Brownfields sites followed by short descriptions of each treatment technology.

Descriptions of the seven contaminant groups included in the tables are included at the end of this appendix.

The appendix is intended to provide general information on Brownfields sites, contaminants, and technologies and is not intended to be all-inclusive. Contaminants and activities associated with common Brownfields site types may not be relevant to every site. Additionally, investigation and remediation technologies may not be appropriate for the listed contaminants in all situations. Stakeholders should consult EPA or state officials, qualified professionals, and other sources of information when proceeding with redevelopment activities.

D.1 What Types of Contaminants are Found at Brownfield Site?

Various contaminants may be present at Brownfields sites. Table D-1 lists common site types and contaminant groups typically associated with the site types followed by short descriptions of each site type.

Table D-1: Typical Contaminant Groups Found by Common Brownfields Site Type

Site Type	Halogenated VOCs	Nonhalogenated VOCs	Halogenated SVOCs	Nonhalogenated SVOCs	Fuels	Metals and metalloids
Agricultural	✓	✓	✓	✓	✓	✓
Battery recycling and disposal						✓
Chemical and dye manufacturing	✓	✓	✓	✓		
Chlor-alkali manufacturing	✓		✓			✓
Cosmetics manufacturing	✓	✓				✓
Drum recycling	✓	✓	✓	✓	✓	✓
Dry cleaning	✓	✓				
Gasoline stations		✓		✓	✓	✓
Glass manufacturing	✓					✓
Hospitals	✓	✓				✓
Incinerators			✓			✓
Landfills, municipal and industrial	✓	✓	✓	✓	✓	✓
Leather manufacturing					✓	✓
Machine shops and metal fabrication	✓	✓	✓		✓	✓
Manufactured gas plants and coal gasification		✓		✓	✓	✓
Marine maintenance	✓	✓			✓	✓
Metal plating and finishing	✓	✓	✓	✓		✓
Metal recycling and automobile salvage	✓		✓	✓	✓	✓
Mining	✓				✓	✓
Painting and automobile body repair	✓	✓			✓	✓
Pesticide manufacturing and use	✓	✓	✓	✓	✓	✓
Petroleum refining and reuse				✓	✓	✓
Pharmaceutical manufacturing	✓	✓				✓
Photographic film manufacturing and development	✓	✓		✓		✓
Plastic manufacturing	✓	✓		✓		✓
Printing and ink manufacturing	✓	✓			✓	✓
Railroad yards	✓	✓	✓	✓	✓	✓
Research and educational institutions	✓	✓	✓			✓
Semiconductor manufacturing	✓	✓				✓
Smelter operations						✓

Site Type	Halogenated VOCs	Nonhalogenated VOCs	Halogenated SVOCs	Nonhalogenated SVOCs	Fuels	Metals and metalloids
Underground storage tanks	√	√			√	√
Vehicle maintenance	√	√			√	√
Wood preservation		√	√	√	√	√
Wood pulp and paper manufacturing	√		√			

Agricultural

Feed supply and other agricultural chemical distribution points may be contaminated with fertilizers, pesticides, and herbicides. Groundwater, drainage area sediments, soils, and nearby surface waters may be contaminated with pesticides and herbicides and could exhibit elevated levels of nitrate from fertilizer runoff. Contamination at agricultural sites may also arise from chemicals used to operate, clean, and maintain farm equipment such as fuel, oil, grease, and solvents.

Battery recycling and disposal

Battery recycling and disposal facilities regenerate, reclaim, and dispose of used batteries. Many batteries contain toxic constituents such as lead, mercury, and cadmium. The metal in used batteries is separated from other battery constituents and processed for reuse. Lead-acid automobile batteries must be broken to reclaim the lead in them. In battery breaking, the top of the battery casing is removed, the sulfuric acid solution inside is drained, and the lead components are separated from the casing. The remaining battery casing may be rinsed before disposal to remove residual lead oxide. Discarded acid and rinse water may be stored in lagoons or tanks. Chemicals may be released to soil and groundwater by leaking tanks or through spillage during the breaking process. Discarded casings may be buried. Any metal remaining on buried, discarded casings may leach into soil and groundwater. The extracted metal must be smelted before it can be reused. Particulate matter emitted by the smelter may contaminate nearby surface soil.

Chemical and dye manufacturing

A wide range of chemicals are used and generated in facilities that manufacture, reformulate, and package chemicals and dyes for commercial and industrial use. The types of contaminants released depend on the raw materials, processes, equipment, and maintenance practices used. Environmental contamination resulting from chemical and dye manufacturing may persist in nearby or downstream surface waters or sediments long after operations have ceased. Moreover, chemical operations can change over time or involve multiple processes; therefore, the sites may be overlaid with several generations of wastes from a variety of products or processes. Many chemical facilities also have quality assurance and research laboratories that use small quantities of toxic chemicals that could contribute to site contamination.

Chlor-alkali manufacturing

Chlor-alkali plants produce a variety of chemicals, including chlorine, caustic soda, hydrochloric acid, sodium hypochlorite, sodium hydrosulfite, salt, hydrogen, sulfur dioxide, and spent sulfuric acid. Three basic processes are used for the manufacture of chlorine and caustic soda from brine: the mercury cell, diaphragm cell, and membrane cell processes. The mercury cell process uses elemental mercury as the cathode and produces mercury-contaminated wastewater, solid waste, and gaseous emissions. The process and waste streams must be carefully controlled to prevent the release of mercury to the environment. The diaphragm cell process may use lead or graphite anodes and asbestos diaphragms and may generate chlorinated hydrocarbons as a by-product. The membrane cell process is the most modern and has economic and environmental advantages. The primary by-product of the membrane cell process is dilute hydrochloric acid, which must be neutralized before it is discharged into the environment.

Cosmetics manufacturing
Cosmetics are mixtures of surfactants, oils, and other ingredients. Cosmetics may contain mineral or metallic and nonmetallic additives. Titanium and zinc are used as sun blockers in sunscreen, for example. The color of makeup is controlled by the concentrations and ratio of black or red iron oxide, titanium dioxide, and zinc oxide. Metal dyes are used in fingernail polish. The uses and concentrations of heavy metals play an important role in cosmetics production and a primary environmental concern at these site types.

Drum recycling
Drum recycling facilities clean used drums for reuse. Soil and groundwater contamination at these facilities may result from leaking and spilling residual chemicals and oils. The variety of chemicals stored in drums makes characterizing potential contaminants difficult. Contaminants could include acids, bases, corrosives, reactive chemicals, flammable materials, and oils. Spillage of paint, paint thinners, and solvents can also contaminate drum recycling facilities.

Dry cleaning
The dry cleaning industry provides garment cleaning and related services such as clothes pressing and finishing. The dry cleaning process is physically similar to the home laundry process, except that clothes are washed in dry cleaning solvent instead of water. Dry cleaning sites may become contaminated because of leaks, spills, and improper disposal of solvents. Two prominent contaminants commonly associated with dry cleaning sites are tetrachloroethene (PCE) and trichloroethene (TCE).

Gasoline stations
Gasoline stations consist of pump islands, underground storage tanks (UST) for fuel, small storage areas, and service areas (which typically contain either hydraulic lifts or pits) for changing automobile engine oil and other maintenance activities. Gasoline and diesel fuel are transferred from bulk tank trucks to large USTs. Spills at the transfer areas and pumps, along with overfilling of and leakage from the USTs, are likely sources of contamination at gasoline stations. The primary contaminants of concern at gasoline stations include petroleum hydrocarbons; benzene, toluene, ethylbenzene, and xylenes (BTEX); and fuel oxygenates such as methyl tertiary butyl ether (MTBE). Service areas typically have small containers of ethylene glycol (coolant), hydraulic oils, lubricants, automotive batteries (lead and acid), and compressed gas, especially acetylene and oxygen cylinders for welding operations. Surface soils may be contaminated because of historical spills or dumping of used lubricants, coolants, and cleaning solvents generated during servicing. Subsurface soils and groundwater, especially in the vicinity of USTs, may also be contaminated because of spills, overfilling, and leaks.

Glass manufacturing
The glass industry consists of firms engaged in primary glass manufacturing and of others that create products using purchased glass. The primary contaminants associated with glass manufacturing are metals such as lead, arsenic, and chromium. Other chemicals used in the glass manufacturing process include hydrofluoric acid, sulfuric acid, and various organic and inorganic solvents. Contaminants may be released to the environment through spills and leaks of raw materials and plant maintenance waste as well as insufficiently treated air emissions.

Hospitals

Hospitals use a variety of toxic chemicals for diagnostic and therapeutic procedures as well as for cleaning and sterilization. Hazardous materials used include chemotherapy and antineoplastic chemicals, formaldehyde, photographic chemicals, radionuclides, solvents, mercury, anesthetic gases, and other toxic or corrosive chemicals. These substances may be released to the environment through leaks and spills, improper disposal of wastes, and insufficient treatment of wastewater. In addition, medical waste incinerators may release mercury into the air.

Incinerators

An incinerator is an enclosed device that uses controlled flame combustion to thermally break down waste to an ash residue that contains little or no combustible material. Incinerators may accept specific wastes such as municipal solid waste, sewage sludge, or medical waste. Contamination from incinerators may be associated with storage and handling of waste materials prior to incineration as well as disposal of ash and other by-products of the combustion process.

Landfills, municipal and industrial

Landfills are now restricted to household garbage, yard wastes, construction debris, and office wastes. Until 1970, however, landfills could accept industrial wastes. Therefore, older landfills are more likely to be contaminated with hazardous chemicals. Even modern landfills can contain a host of chemicals from household wastes such as oils, paints, solvents, corrosive cleaners, batteries, and gardening products. Illegal dumping at landfills can also be a source of contamination. Improperly designed landfills have a higher likelihood of surface soil and groundwater contamination and may trap explosive levels of methane gas and hydrogen sulfide in the soil cover.

Leather manufacturing

Leather tanning is the process of converting raw hides or skins into leather. Hides and skins absorb tannic acid and other chemical substances that prevent them from decaying, make them resistant to wetting, and keep them supple and durable. Tanning is essentially the reaction of collagen fibers in the hide with tannins, chromium, alum, or other chemical agents. The most common tanning agents used in the United States are trivalent chromium and vegetable tannins extracted from certain tree barks. Alum, syntans (manmade chemicals), formaldehyde, glutaraldehyde, and heavy oils are also used as tanning agents.

Machine shops and metal fabrication

The fabricated metal product industry has facilities that generally perform two functions: forming metal shapes and performing metal finishing operations, including surface preparation. Metal fabricators produce ferrous and nonferrous metal products. Machining and other metal working may generate waste metals, lubricants, cleaners, and other materials. These substances may contaminate soil, groundwater, and surface water if they are spilled, leaked, or improperly disposed.

Manufactured gas plants and coal gasification

Manufactured gas has been produced as a fuel source from coal and oil since the early 1800s. Typically, coal or oil is heated and the resulting volatilized gases are distilled to produce natural gas. Depending on the process design, various by-products can be recovered, including anthracene, benzene, cresol, naphthalene, paraffin, phenol, toluene, and xylenes. Waste products from manufactured gas operations include coal fines, coal tar, cyanide salts, hydrogen sulfide gas, ammonia, and wastewater. Leakage and spillage from storage drums or tanks may contaminate surface and subsurface soils, sediments, surface water, and groundwater.

Marine maintenance

Marine maintenance industry establishments engage in general painting and repairing ship or boat structures and engines or power plants. Activities may include painting, servicing engines, structural repairs, engine or power plant maintenance, electroplating, air conditioning and refrigeration service, electrical repair, and other cleaning and repair services. A number of chemicals may be used at marine maintenance facilities, including chemical paint strippers, blast media, antifouling paints, solvents, carburetor cleaner, cutting fluids, acids and alkalis, cyanide, heavy metal baths, fiberglass and reinforcement, resins, and mold release agents.

Metal plating and finishing

Metal plating operations improve a product's performance (for example, its durability or corrosion resistance) or appearance. Metal components are first cleaned (using solvents or water-based detergents) to remove dirt and oils from manufacturing operations. The metal components are subsequently etched, plated, and finished in a series of vats or baths. Common plating metals include cadmium, chromium, copper, gold, nickel, silver, and their alloys. Spillage during plating and cleaning operations and leakage or overflows from storage tanks and process vats may contaminate concrete floors and underlying soils. Groundwater may also be contaminated by heavy metals, cyanide, and solvents.

Metal recycling and automobile salvage

Automobile salvage yards recover usable parts, scrap metal, and other recyclable materials from old or wrecked automobiles. Nonrecyclable materials are stored on site or sent to a municipal landfill. Metal recyclers purchase metal from a variety of sources and sort and process the scrap metal for resale. Metals commonly salvaged by these facilities include iron, steel, copper, brass, and aluminum. Sites may contain non-recyclable wastes and contaminated materials. Contaminated "auto fluff," a fibrous residue containing plastics, fabrics, and other materials, may be present at sites that shred materials for salvage. Depending on the type of recycling operation conducted at a site, the surrounding soils and groundwater may be contaminated with heavy metals, asbestos, polychlorinated biphenyl (PCB) oils, hydraulic fluids, lubricating oils, fuels, solvents, tetraethyl lead, methyl tertiary-butyl ether (MTBE), 1,4 dioxane, glycols and alcohols (drum antifreeze), and phthalates.

Mining

There are three general steps in the mining process: extraction, beneficiation, and processing. Extraction of the mineral value from the rock or matrix is the initial step in the operation. Beneficiation is the processing of extracted materials to clean or concentrate the product either for use as a final product or in preparation for further processing. Beneficiation may involve physical (such as milling) or chemical (such as leaching) separation processes or both. Processing is conducted after beneficiation to further extract or refine the material and prepare it for specific uses. Processing may include a variety of operations such as smelting, refining, roasting, and digesting. Chemical contamination at mining sites may result from acidic, metal-laden mine drainage. Spilled, leaked, or improperly disposed of petroleum, lubricants, and other industrial chemicals may also result in site contamination.

Painting and automobile body repair

Paint shops and automobile body repair shops paint various plastic and metal products and fix truck and automobile body parts. Damaged automobile body parts are replaced or repaired with fillers and are then sanded, primed, and painted. The shops may use cutting torches, welding equipment, solvents and cleaners, fiberglass, various polymers and epoxy compounds, and sand or grit blasting. Gasoline and diesel from vehicle fuel tanks, solvents, cleaners, acids, and paints may be leaked or spilled, contaminating soils and groundwater. Typical contaminants include toluene, acetone, perchloroethylene, xylene, gasoline and diesel fuel, carbon tetrachloride, and hydrochloric and phosphoric acids.

Pesticide manufacturing and use

A pesticide is any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest. The term "pesticide" also applies to herbicides, fungicides, and various other substances used to control pests. Spillage, leakage, and improper storage or disposal of pesticides may result in their release to the environment. Sites may also be contaminated with properly applied but persistent pesticides. Because of the wide variety of pesticides and applications, facilities manufacturing or using pesticides may be contaminated with a broad range of chemicals.

Petroleum refining and reuse
Oil production facilities consist of oil drilling, refining, storage, transfer, transport, and recycling facilities. Typical materials present at these facilities include crude, fuel, and motor oils as well as waste oils. Production processes at these facilities may contaminate soils with sludges, acids, and waste oil additives as well as co-contaminants such as PCBs when spills, leaks, or improper disposal practices occur. In some cases, disposal pits may contain thick, tarry sludges with very high pH values. Groundwater and deeper soil may be contaminated with metals and lighter oil fractions such as BTEX.

Pharmaceutical manufacturing
The pharmaceutical industry manufactures bulk pharmaceutical intermediates and active ingredients that are further processed into finished products. Chemicals used in the manufacturing process vary according to the desired product and the process type. Equipment must be thoroughly cleaned between processing operations for different products. VOCs are used as solvents at various stages of the manufacturing process. Because of the purity required for products, spent solvent is not usually reused in pharmaceutical manufacturing. However, it may be sold for nonpharmaceutical use or destroyed via incineration. The ten contaminants most commonly discharged in pharmaceutical wastewater are methanol; ethanol; acetone; isopropanol; acetic acid; methylene chloride; formic acid; ammonium hydroxide; N,N-dimethylacetamide; and toluene.

Photographic film manufacturing and development
Photographic film is coated with an emulsion containing light-sensitive silver halide crystals. Once film has been exposed, it must go through a series of chemical processes to bring out the images. Various chemicals are used as developers and fixing solutions, including hydroquinone, catechols, aminophenols, acetic acid, muriatic (hydrochloric) acid, and sodium or ammonium thiosulfate. Silver solutions are often generated during the photographic development processes.

Plastic manufacturing
Almost all plastics are made from petroleum. Plastics are polymers, which are very long chains of molecules that consist of subunits (monomers) linked together by chemical bonds. Monomers of petrochemical plastics are not typically biodegradable. Wastes generated by the industry include polymers, phthalates, cadmium, solvents, resins, chemical additives, and VOCs.

Printing and ink manufacturing
The printing industry consists of firms engaged in printing using one or more common processes such as lithography, letterpress, flexography, gravure, and screen printing. Contamination may result from spills, leaks, and improper disposal of excess chemicals and wastes, including ink constituents such as metals, cleaners, and solvents used during printing and production processes.

Railroad yards
Railroad yards may consist of any combination of track and switching areas, engine maintenance buildings, engine fueling areas, bulk and container storage and transfer stations, and storage areas for materials used in track and engine maintenance. Materials used at railroad yards include diesel fuel, paint, solvents and degreasing agents, PCB oils, and creosote. Spills, leaks, or dumping of these compounds may contaminate soil, groundwater, and sediment. Chemical spills and leaks during loading and unloading of tanker and freight cars can also contaminate a railroad yard. Virtually any type of chemical contamination could be present because of the variety of chemicals used at and transported through railroad yards.

Research and educational institutions
Academic institutions are often similar to small cities, as they may have research laboratories, automobile repair facilities, power plants, wastewater treatment plants, hazardous waste management and trash disposal, asbestos management, drinking water supply facilities, grounds maintenance, and incineration facilities. Educational institutions typically generate small quantities of a variety of wastes, including inorganic acids, organic solvents, metals and metal dust, photographic waste, waste oil, paint, heavy metals, and pesticides.

Semiconductor manufacturing
The semiconductor manufacturing industry is a subset of the electronics manufacturing industry and produces integrated circuits or "chips." Contamination on semiconductor chips is one of the primary reasons that they fail; therefore, chips are cleaned before and after many of the steps in manufacturing. Chemicals used in the manufacturing process include various acids, ethylene glycol, hydroxide solutions, halogen gases, fluorocarbons, chlorine, and various organic solvents.

Smelter operations
The primary purpose of smelting is to produce iron and steel from iron ore. Smelting is also used to extract copper and other base metals from raw ores. Contamination from smelting operations often takes the form of deposition of airborne metals, asbestos, and sulfur compounds in areas surrounding smelters. Contamination may also result from improper storage and disposal of raw ores or by-product slag.

Underground storage tanks
A UST is a tank and any underground piping connected to a tank where at least 10 percent of the combined volume is under the ground. USTs often contain petroleum products, gasoline, or other chemicals. Faulty installation or inadequate operating and maintenance procedures can cause USTs to release their contents into the environment. The greatest potential hazard from leaking USTs is that petroleum fuels, fuel additives, or other hazardous substances can seep into soil and contaminate groundwater.

Vehicle maintenance
Vehicle maintenance involves handling and managing a wide variety of materials and wastes, including oils, batteries, refrigerants, antifreeze, solvents, asbestos, and fuels. Improper management and disposal of wastes as well as leaks from fuel and waste storage containers may result in contamination of vehicle maintenance facilities.

Wood preservation
Wood preservation sites typically consist of wood preparation facilities, chemical storage tanks, chemical treatment areas (including high-pressure vessels in many cases), drip or drying areas, and wood storage areas. Wood is treated with preservative chemicals either by dipping the wood into a chemical bath or by injecting chemicals into the wood under pressure. Storage tanks at wood preservation sites could contain creosote, pentachlorophenol, or chrome-copper arsenate (CCA) solutions for wood treatment. These chemicals could enter the environment if the tanks were overfilled or leaked. Contaminated water squeezed from wood during processing and retort sludge may have spilled on the ground, contaminating soil and groundwater. As treated wood is transferred from the treatment area to the drying area, chemicals may drip onto soil and contaminate the soil and groundwater. Likewise, drippage in drying areas, especially in older operations where pressure treatment may not have been used, could contaminate soil. Runoff from site could also contaminate nearby surface waters.

Wood pulp and paper manufacturing
The pulp and paper industry produces commodity grades of wood pulp, printing and writing paper, sanitary tissue, industrial-type paper, containerboard, and boxboard using cellulose fiber from timber or purchased or recycled fibers. The two steps involved are pulping and paper or paperboard manufacturing. Pulping is the process of dissolving wood chips into individual fibers using chemical, semi-chemical, or mechanical methods. Pulping is the

major source of environmental impacts in the industry. Chlorinated organic compounds in wastewater sludge from the pulp plant are of particular concern because of their tendency to partition from effluent to solids. Improper treatment or disposal of wastes may result in contamination being released to the environment. Spills and leaks of process and waste chemicals are other common sources of contamination at pulp mills. Air emissions are also problematic at pulp mills, which are typically noted for their unpleasant odors.

D.2 What Technologies May Be Used to Investigate Contaminants at Brownfields Sites?

Table D-2 lists technologies that may be used to analyze contaminants commonly found at Brownfields sites followed by short descriptions of each investigation technology.

Table D-2: Technologies for Analyzing Contaminants at Brownfields Sites

Investigation Technology	Halogenated VOCs	Nonhalogenated VOCs	Halogenated SVOCs	Nonhalogenated SVOCs	Fuels	Metals and metalloids	Explosives
Amperometric and Galvanic Cell Sensor	✓	✓				✓	
Anodic Stripping Voltammetry						✓	
Atomic Absorption Spectroscopy						✓	
Catalytic Surface Oxidation	✓	✓					
Chemical Colorimetric Kits	✓	✓	✓	✓	✓	✓	✓
Cone Penetrometer Testing *	✓	✓	✓	✓	✓	✓	✓
Detector Tubes	✓	✓					
Electrical Conductivity Probe *	✓	✓	✓	✓	✓	✓	✓
Electromagnetic Conductivity *						✓	
Explosimeter	✓	✓	✓	✓	✓	✓	✓
Fiber Optic Chemical Sensors *	✓		✓		✓		
Field Bioassessment	✓	✓	✓	✓		✓	✓
Field-Portable X-Ray Fluorescence *						✓	
Flame Ionization Detector	✓	✓		✓	✓		
Fluorescence Spectrophotometry						✓	
Fourier Transform Infrared Spectroscopy	✓	✓			✓		
Free Product Sensors	✓			✓	✓		
Fuel Fluorescence Detector *					✓		
Gas Chromatography/ Mass Spectrometry	✓	✓	✓	✓	✓		✓
Ground Penetrating Radar *						✓	
Hydraulic Profiling Tool *	✓	✓	✓	✓	✓	✓	✓
Immunoassay Colorimetric Kits	✓	✓	✓	✓	✓	✓	✓
Inductively Coupled Plasma-Atomic Emission Spectroscopy						✓	
Infrared Spectroscopy	✓	✓	✓	✓	✓		
Ion Chromatography						✓	
Ion Mobility Spectrometer	✓	✓	✓	✓	✓		✓
Ion Trap Mass Spectrometry	✓	✓	✓	✓			

Investigation Technology	Halogenated VOCs	Nonhalogenated VOCs	Halogenated SVOCs	Nonhalogenated SVOCs	Fuels	Metals and metalloids	Explosives
Laser-Induced Fluorescence (LIF) Probe (UVOST, ROST, TarGOST) *					√		
Magnetometry						√	
Membrane Interface Probe with Electron Capture Detectors (ECD) *	√	√					
Membrane Interface Probe with Flame Ionization Detector (FID) *		√			√		
Membrane Interface Probe with Halogen Specific Detector (XSD) Detector *	√						
Membrane Interface Probe with Photoionization Detector (PID)	√	√			√		
Near Infrared Reflectance/ Transmittance Spectroscopy	√	√					
Photoionization Detector (PID) *	√	√	√	√	√		
Piezoelectric Sensors	√	√					
Raman Spectroscopy/ Surface-Enhanced Raman Scattering (SERS)	√	√	√	√	√		
Room-Temperature Phosphorimetry		√	√				
Scattering/Absorption LIDAR	√	√					
Semiconductor Sensors	√	√					
Soil-Gas Analyzer Systems	√	√	√	√	√		√
Solid/Porous Fiber Optic	√	√	√		√		
Synchronous Luminescence/ Fluorescence	√	√	√	√	√		
Thin-Layer Chromatography				√			
Titrimetry Kits					√		
Toxicity Tests	√	√	√	√		√	√
Ultraviolet Fluorescence	√	√		√			
Ultraviolet Visible Spectrophotometry	√	√		√	√		
Waterloo Advanced Profiling System *	√	√	√	√	√	√	√

* Indicates a direct-sensing technology. Direct Sensing Probes, which can be pushed or hammered into the subsurface in the field, are designed to collect real-time information that can support dynamic work strategies and decisions made in the field. The density of information provided by these probes makes them useful for high-resolution imaging of contaminant source areas and plume geometry

Amperometric and Galvanic Cell Sensor

Amperometric and galvanic cell sensors involve ambient air quality monitoring of VOCs. Amperometric and galvanic cell sensors measure an electrochemical response when the sensor comes into contact with the analyte of interest. An internal pump draws an air sample into the analyzer. Each probe contains a sensor that is specifically sensitive to a particular gas or vapor. These sensors typically consist of electrodes in contact with an electrolyte-saturated insulator. Selective membranes allow the gas of interest to enter the insulator, and redox reaction on the sensing-electrode surface generates a current that is proportional to the analyte concentration. When an analyte is present, it will absorb to the thin-film sensor, which undergoes a change in electrical resistance proportional to the mass of analyte absorbed onto its surface. This change is measured and converted to a vapor concentration that is displayed on the readout of the analyzer.

Anodic Stripping Voltammetry

Anodic stripping voltammetry (ASV) is an electrochemical technique in which information about an analyte is derived from measurement of current as a function of applied potential. The measurement is performed in an electrochemical cell under polarizing conditions on a working electrode, which is normally a mercury or gold film-coated, glassy carbon electrode. Analysis involves a two-step process consisting of electrolysis and stripping. The analyte of interest is reduced and collected at the working electrode and then stripped off and measured. The reduction step is much longer than the stripping step, and the increase in the signal to noise allows low-concentration solutions to be measured. The advantage of ASV is the ability to distinguish between different oxidation states of the same metal. Anodic stripping voltammetry, along with similar potentiometric techniques (including constant current stripping voltammetry and cathodic stripping voltammetry), has been used for measurement of trace levels of a variety of metals.

Atomic Absorption Spectroscopy

Atomic absorption (AA) spectroscopy involves the absorption of radiant energy by neutral atoms in the gaseous state. Since samples are usually liquids or solids, the atoms or ions in the analyte must be vaporized in a flame or graphite furnace. The atoms absorb ultraviolet or visible light and make transitions to higher electronic energy levels. The analyte concentration is measured from the amount of absorption. More sophisticated instruments can have more than one channel for simultaneous measurement of more than one element. Multi-element sequential instruments can be programmed to automatically determine chosen elements sequentially.

Catalytic Surface Oxidation

Catalytic surface oxidation is a combustible gas indicator. Instruments can be used in the immediate environment or can draw samples from remote areas through sampling lines or probes. Catalytic surface oxidation devices operate in similar fashion to explosimeters.

Chemical Colorimetric Kits

Chemical colorimetric kits are self-contained portable kits for analyzing soil or water samples for the presence of a variety of inorganic and organic compounds. These tests require no instrumentation and can be performed in the field with minimal training. They should only be used as an indication or screening device and are safe for thermally sensitive compounds. Colorimetry involves mixing of reagents of known concentrations with a test solution in specified amounts that result in chemical reactions in which the absorption of radiant energy (color of the solution) is a function of the concentration of the analyte of interest. At the simplest level, concentrations can be estimated with visual comparators.

Cone Penetrometer Testing (direct sensing)

Cone Penetrometer Testing (CPT) is a direct-push technology that uses hydraulic pressure to advance sampling devices and geotechnical and analytical sensors into the subsurface. Used for approximately the last 50 years for geotechnical applications, its use for site characterization is relatively new.

Detector Tubes
Detector tubes contain a reagent located on absorbing material that is specifically sensitive to a particular vapor or gas. Operation generally involves inserting the tube into a hand-held pump. As the handle of the pump is pulled, ambient air is drawn inside the tube where it contacts the reagent and the reagent then changes color. The color will move up the tube to indicate the concentration (indicated by a calibration mark on the tube).

Electrical Conductivity Probe (direct sensing)
An Electrical Conductivity (EC) Probe is a direct-push technology that measures electrical properties in soil to determine relative vertical variations in lithology.

Electromagnetic Conductivity (direct sensing)
Electromagnetic Conductivity (EM) is a surface geophysics technology that measures the conductivity of the subsurface, which includes soil, groundwater, rock, and objects buried in the ground.

Explosimeter
Explosimeters are used to verify flammable gas concentration in the atmosphere. Instruments can be used in the immediate environment or can draw samples from remote areas through sampling lines or probes. The instrument operates by the catalytic action of a heated filament in contact with combustible gases. The filament is heated to operating temperature by passage of an electrical current. When the gas sample contacts the heated filament, combustion on the surface raises the temperature in proportion to the quantity of combustibles in the sample. A sensor measures the change in electrical resistance caused by the temperature increases. A signal is processed and displayed as the percentage of the combustible gas present to the total required to reach the lower explosive limit (LEL) or the percent combustible gas by volume.

Fiber Optic Chemical Sensors (direct sensing)
Fiber optic chemical sensors (FOCS) operate by transporting light by wavelength or intensity to provide information about analytes in the environment surrounding the sensor. The environment surrounding a FOCS is usually air or water. FOCS can be categorized as intrinsic or extrinsic. Extrinsic FOCS simply use an optical fiber to transport light. An example is the laser induced fluorescence (LIF) cone penetrometer. The optical fiber is only a conduit for the laser induced fluorescence to be transported to an uphole detector. In contrast, intrinsic FOCS use the fiber directly as the detector. A portion of the optical fiber cladding is removed and replaced with a chemically selective layer. The sensor is then placed directly into the medium to be analyzed. Interaction of the analyte with the chemically selective layer creates a change in absorbance, reflectance, fluorescence, or light polarization. The optical change is then detected by measuring changes in the light characteristic carried by the optical fiber.

Field Bioassessment
Field bioassessments provide an indication of the potential for ecological risk (or lack of) that can be used to: (1) estimate the likelihood that ecological risk exists; (2) identify the need for site-specific data collection efforts; and (3) focus site-specific ecological risk assessments where warranted. Initial screening-level assessments are not designed or intended to provide definitive estimates of actual risk or generate cleanup goals, and are not based on site-specific assumptions. Rather, their purpose is to assess the need to conduct a detailed ecological risk assessment for a particular site.

Field-Portable X-Ray Fluorescence (direct sensing)
Field portable X-ray fluorescence (FPXRF) is a hand-held device for simultaneously measuring a number of metals in various media. FPXRF units that run on battery power and use a radioactive source were developed for use in analysis for lead-based paint and now are accepted as a stand-alone technique for analysis of lead. In response to the growing need for field analysis of metals at hazardous waste sites, many of these FPXRF units have been adapted for use in the environmental field. The field-rugged units use analytical techniques that have been

developed for analysis of numerous environmental contaminants in soils. They provide data in the field that can be used to identify and characterize contaminated sites and guide remedial work, among other applications. In addition, FPXRF units are now manufactured with non-radioactive sources, making them available for use nationwide without having to address radioactive source use permitting requirements.

Flame Ionization Detector

Portable flame ionization detector (FID) instruments detect compounds by using a sampling pump to feed air into a mixing chamber. The mixture is ignited as it passes over a pure hydrogen flame that breaks down the organic molecules and produces ions (atoms or molecules that have gained or lost electrons and thus have a net positive or negative charge). The ions gather on a collection plate, where a current is generated as a result of the high voltage applied across the detector and the organic ions and electrons present in the gas. The magnitude of the current is proportional to the concentration of organic vapors in the gas. FIDs are also commonly used as detectors in portable gas chromatographs and have several advantages over photoionization detectors (PIDs), including a wider measuring range and response to all hydrocarbons and methane. In addition, FIDs do not give false positive readings to water vapor.

Fluorescence Spectrophotometry

Spectrophotometry encompasses a number of techniques involving measurement of the absorption spectra of narrow band widths of radiation. A simple spectrophotometer consists of (1) a radiation source; (2) a monochromator, containing a prism or grating that disperses the light so that only a limited wavelength or frequency range is allowed to irradiate the sample; and (3) a detector that measures the amount of light transmitted by the sample.

Fourier Transform Infrared Spectroscopy

Fourier transform infrared (FTIR) spectroscopy measures the absorption caused by infrared active molecules. This technique involves generation of a light beam over a range of wavelengths in the near-infrared (IR) portion of the spectrum. The beam passes through a parcel of atmosphere in which chemical species absorb IR radiation at characteristic wavelengths. The beam is reflected directly back on itself to the receiver/transmitter. The received spectrum is compared with a library spectrum for each chemical compound of interest so that the compounds present can be identified and qualified. Data are analyzed using a computer and a software package.

Free Product Sensors

Free product sensors are designed to give an accurate measurement of liquids lighter than water. A 1.5-inch (38-millimeter) diameter probe includes a highly visible light with an audible signal to indicate the presence of water and light immiscible liquids.

Fuel Fluorescence Detector (direct sensing)

A Fuel Fluorescence Detector (FFD) is a direct push ultraviolet fluorescence (UVF) probe that is used primarily for investigating fuel impacts. The probe contains a UV lamp that causes polycyclic aromatic hydrocarbons (PAHs) in fuels to fluoresce. Fluorescence is captured by the probe and converted to an electronic signal which corresponds to concentration.

Gas Chromatography/ Mass Spectrometry

Coupling mass spectrometers with gas chromatography (GC) systems allows separation and subsequent determination of components of highly complex mixtures with a high degree of certainty. Similar compounds may be retained for different lengths of time on the GC column, allowing separate identification and quantitation, even if the two compounds, or fragments of compounds, have similar mass to charge ratios. Retention time thus provides a secondary source of identification. Recently, manufacturers of mass spectrometers, particularly spectrometers coupled with GC systems, have significantly reduced their overall size and have increased durability.

These changes allow what was once a laboratory bench-top instrument to be portable (or transportable), and sufficiently rugged to perform field analysis.

Ground Penetrating Radar (direct sensing)
Ground penetrating radar (GPR) is most commonly used for locating buried objects (such as tanks, pipes, and drums); mapping the depth of the shallow water table; identifying soil horizons and bedrock subsurface; mapping trench boundaries; delineating karst features and the physical integrity of manmade earthen structures; and selecting locations for installation of suction samplers in the vadose zone.

Hydraulic Profiling Tool (direct sensing)
The Hydraulic Profiling Tool (HPT) is a probe that measures the relative hydraulic properties of unconsolidated subsurface deposits.

Immunoassay Colorimetric Kits
Immunoassay (IA) colorimetric kits involve field screening of individual contaminants. IA technology relies on an antibody that is developed to have a high degree of sensitivity to the target compound. This antibody's high specificity is coupled within a sensitive colorimetric reaction that provides a visual result. The intensity of the color formed is inversely proportional to the concentration of the target analyte in the sample. The absence or presence is determined by comparing the color developed by a sample of unknown concentration with the color formed with the standard containing the analyte at a known concentration.

Inductively Coupled Plasma-Atomic Emission Spectroscopy
Atomic emission spectroscopy (AES) measures the optical emission from excited atoms to measure the analyte concentration. Analyte atoms in solution are aspirated into the excitation region where they are desolvated, vaporized, and atomized by a flame, discharge, or plasma. High-temperature atomization sources are used to promote the atoms into high energy levels causing them to decay back to lower levels by emitting light. Inductively coupled plasma (ICP) is a very high temperature (7,000 to 8,000 °K) excitation source that efficiently desolvates, vaporizes, excites, and ionizes atoms. The standard ICP-AES instrument is a radial configuration. Recently introduced models have an axial configuration, which can achieve lower detection limits. Each configuration has advantages and disadvantages; radial configurations have a proven track record but higher detection limits, while axial configurations have lower detection limits but may not be able to reproduce results as consistently.

Infrared Spectroscopy
Infrared (IR) spectroscopy has been an established bench-top laboratory analytical technique for many years. It identifies and quantitates compounds through the use of their IR absorption spectra. Another use of the IR spectra is found with recently developed video cameras. These cameras use IR absorption to image the absorbing compounds on a video tape. The image appears as a cloud on the video and is used to monitor vapor behavior, but the instrument does not identify or quantitate the individual compounds.

Ion Chromatography
Ion mobility spectrometry (IMS) is a technique used to detect and characterize organic vapors in air. Ion mobility spectrometry analysis is based on analyte separations resulting from ionic mobilities rather than ionic masses. A sampling pump draws air through a semipermeable membrane, which is selected to exclude or attenuate possible interferents. The sample is ionized in a reaction region through interaction with a weak plasma of positive and negative ions produced by a radioactive source. A shutter grid allows periodic introduction of the ions into a drift tube, where they separate based on charge, mass, and shape with the arrival time recorded by a detector. The identity of the molecules is determined using a computer to match the signals to IMS signatures held in memory. If the IMS signature is known, it is also possible to program the instrument to detect specific compounds of interest.

IMS operates at atmospheric pressure, a characteristic that has practical advantages over mass spectrometry, including smaller size, lower power requirements, less weight, and ease of use.

Ion Mobility Spectrometer

Ion mobility spectrometry (IMS) is a technique used to detect and characterize organic vapors in air. Ion mobility spectrometry analysis is based on analyte separations resulting from ionic mobilities rather than ionic masses. A sampling pump draws air through a semipermeable membrane, which is selected to exclude or attenuate possible interferents. The sample is ionized in a reaction region through interaction with a weak plasma of positive and negative ions produced by a radioactive source. A shutter grid allows periodic introduction of the ions into a drift tube, where they separate based on charge, mass, and shape with the arrival time recorded by a detector. The identity of the molecules is determined using a computer to match the signals to IMS signatures held in memory. If the IMS signature is known, it is also possible to program the instrument to detect specific compounds of interest. IMS operates at atmospheric pressure, a characteristic that has practical advantages over mass spectrometry, including smaller size, lower power requirements, less weight, and ease of use.

Ion Trap Mass Spectrometry

Ion trap mass spectrometry determines the masses of atoms or molecules found in a solid, liquid, or gas, particularly VOCs. It uses three electrodes to trap ions in a small volume. The mass analyzer consists of a ring electrode separating two hemispherical electrodes. A mass spectrum is obtained by changing the electrode voltages to eject the ions from the trap. The advantages of the ion trap mass spectrometer include compact size and the ability to trap and accumulate ions to increase the signal-to-noise ratio of a measurement.

Laser-Induced Fluorescence (LIF) Probe (UVOST, ROST, TarGOST) (direct sensing)

Laser-induced Fluorescence (LIF) is a method for real-time, in situ, field screening of hydrocarbons in subsurface soils and groundwater. The technology is intended to provide highly detailed, qualitative to semi-quantitative information about the distribution of subsurface petroleum contamination. LIF sensors are deployed as part of integrated, mobile CPT systems that are operated by highly trained technicians familiar with the technology and its application. Examples of LIF probes include UltraViolet Optical Screening Tools (UVOST), Rapid Optical Screening Tools (ROST), and Tar Specific Green Optical Screening Tools (TarGOST).

Magnetometry (direct sensing)

Magnetometry is a surface geophysics technology that is used for locating subsurface iron, nickel, cobalt and their alloys, which are typically referred to as ferrous materials.

Membrane Interface Probe with Electron Capture Detectors (ECD) (direct sensing)

A membrane interface probe (MIP) is a semi-quantitative, field-screening device that can detect VOCs in vadose and saturated soils. It is used in conjunction with a direct-push technology (DPT) platform, such as a CPT rig or a rig that uses a hydraulic or pneumatic hammer to drive the MIP to the depth of interest to collect samples of vaporized compounds. The probe captures the vapor sample, and a carrier gas transports the sample to the surface for analysis by a variety of field or laboratory analytical methods. The ECD is used to detect chlorinated VOCs such as tetrachloroethene (PCE) and trichloroethene (TCE).

Membrane Interface Probe with Flame Ionization Detector (FID) (direct sensing)

An MIP is a semi-quantitative, field-screening device that can detect VOCs in vadose and saturated soils. It is used in conjunction with a DPT platform, such as a CPT rig or a rig that uses a hydraulic or pneumatic hammer to drive the MIP to the depth of interest to collect samples of vaporized compounds. The probe captures the vapor sample, and a carrier gas transports the sample to the surface for analysis by a variety of field or laboratory analytical methods. The FID is used to detect straight chained hydrocarbons such as methane and butane.

Membrane Interface Probe with Halogen Specific Detector (XSD) Detector (direct sensing)

An MIP is a semi-quantitative, field-screening device that can detect VOCs in vadose and saturated soils. It is used in conjunction with a DPT platform, such as a CPT or a rig that uses a hydraulic or pneumatic hammer to drive the MIP to the depth of interest to collect samples of vaporized compounds. The probe captures the vapor sample, and a carrier gas transports the sample to the surface for analysis by a variety of field or laboratory analytical methods. The XSD is used to detect halogenated solvents such as chlorobenzene, chloroform and 1,2-dichloroethene (1,2-DCE).

Membrane Interface Probe with Photoionization Detector (PID) (direct sensing)

An MIP is a semi-quantitative, field-screening device that can detect VOCs in vadose and saturated soils. It is used in conjunction with a DPT platform, such as a CPT rig or a rig that uses a hydraulic or pneumatic hammer to drive the MIP to the depth of interest to collect samples of vaporized compounds. The probe captures the vapor sample, and a carrier gas transports the sample to the surface for analysis by a variety of field or laboratory analytical methods. The PID is used to detect aromatic hydrocarbons, such as BTEX compounds.

Near Infrared Reflectance/ Transmittance Spectroscopy

Near infrared reflectance/transmittance spectroscopy involves airborne remote sensing identification of subsurface VOC contamination. It uses reflectance signals resulting from bending and stretching vibrations in molecular bonds between carbon, nitrogen, hydrogen, and oxygen. Calibration is required to correlate the spectral response of each sample at individual wavelengths to known chemical concentrations from laboratory analysis.

Photoionization Detector (PID) (direct sensing)

The portable hand-held PID is composed of an ultraviolet lamp that emits photons (a quantum unit of light energy) that are absorbed by the analyte in an ionization chamber. Ions produced during this process are collected by electrodes. The current generated provides a measure of the analyte concentration. PIDs are commonly used as detectors in portable gas chromatographs (GCs, which separate the specific analyte types). Because only a small fraction of the analyte molecules are actually ionized, this method is considered nondestructive, allowing it to be used in conjunction with another detector to confirm analysis results. Confirmation is easily accomplished by connecting the exhaust port of the PID to a FID or ECD.

Piezoelectric Sensors

Piezoelectric sensors screen for chlorinated hydrocarbons and other VOC gases. Sensors using piezoelectric materials develop an electrical response to changes in pressure. Typically, oscillating materials are used as sensitive gravimetric detectors. Selective coatings allow specific organic solvent vapors to be sorbed on the crystal. The increased mass of the crystal resulting from sorption changes the frequency of oscillation, which can be correlated with concentration.

Raman Spectroscopy/ Surface-Enhanced Raman Scattering (SERS)

Raman spectroscopy encompasses a variety of techniques that involve detection and analysis of the scattering of radiation. Raman spectroscopy is the measurement of the wavelength and intensity of inelastically scattered light from molecules. When electromagnetic radiation passes through matter, most of the radiation continues in its original direction but a small fraction is scattered in other directions.

Room-Temperature Phosphorimetry

Room-temperature phosphorimetry is based on detecting the phosphorescence emitted from organic compounds absorbed on solid substrates at ambient temperatures. (Conventional phosphorimetry requires cryogenic [low temperature] equipment.) Instrument design is similar to fluorescence techniques.

Scattering/Absorption LIDAR
Light detection and ranging (LIDAR) measurements of atmospheric trace gases have historically employed two basic techniques: elastic scattering differential absorption LIDAR (DIAL) and inelastic scattering Raman LIDAR.

Semiconductor Sensors
Semiconductor sensors screen for chlorinated hydrocarbons in water and gas samples. Semiconductor sensors are designed to respond electrically to the substance of interest.

Soil-Gas Analyzer Systems
Soil-gas sampling systems have been developed as part of multiple-use sampling tools. The Simulprobe soil sampler can be used in its drive and sniff mode, allowing soil gases to be continuously collected while the sampler is advanced into the subsurface. Based on the field screening of the soil gas sample, a collocated soil sample can be immediately collected. Similarly, the ConeSipper can be used to collect soil gas samples in the vadose zone, and then collect groundwater samples as the tool advances below the water table. Finally, most dual-tube sampling systems can be used for alternating soil and soil gas sampling.

Solid/Porous Fiber Optic
Fiber optics is a technique that transmits light through long, thin, flexible fibers of glass, plastic, or other transparent material. Parallel fibers bundled together can be used to transmit complete images. The most common fiber-optic sensors send an excitation signal from a light source that is transmitted down the cable to a sensor. The sensor fluoresces and provides a constant-intensity light source that is transmitted back up the cable and detected as the return signal. The intensity of the return signal is reduced if the target contaminant is present. (The intensity of the light that is recorded by the detector is inversely proportional to the concentration.) The configuration of a fiber-optic sensor system requires a simple light source, a detector, and simple optics to focus and guide light into and out of the fiber-optic conduit. The same fiber can be used to transmit the probe beam to the sensor, as well as to carry the modulated signal back to the detector. At the proximal end of the fiber is a small calculator-size box of optics and electronics that contains both the light source and the signal detection equipment. (Generally, the fiber optic cable is attached to a spectrophotometer or a fluorometer, which contains both a light source and a detector.) The electronics box is configured to a small central processing unit or a lap-top computer that collects and analyzes the sensor signals and provides useful information on the analyte concentration. At the distal and working end of the fiber is the sensor, normally encased in a protective metal shield to prevent damage.

Synchronous Luminescence/ Fluorescence
Synchronous luminescence/fluorescence involves semi-quantitative analysis of PAHs and field screening of BTEX. Synchronous luminescence/fluorescence involves the use of both emission and excitation monochromators to record the luminescence signal, which allows greater selectivity in the analysis of environmental samples. Instruments use a sweeping motion, similar to using a metal detector, to scan the site. During this operation, light of a narrow wavelength is projected from the detector head onto the surface being inspected, causing excitation fluorescence of the targeted materials. Low-level light energy released from the excited material's fluorescence is: (1) filtered to reject unwanted wavelengths of reflected and ambient light, (2) amplified, (3) converted to a video signal, and (4) relayed to the monitor. Light areas displayed on the monitor's darker background indicate the presence of contamination to the operator.

Thin-Layer Chromatography
Thin-layer chromatography consists of a stationary phase immobilized on a glass or plastic plate and a solvent. The sample, either liquid or dissolved in a volatile solvent (n-butanol and cellulose acetate), is deposited as a spot on the stationary phase. The constituents of a sample can be identified by simultaneously running standards with the unknown. One edge of the plate is then placed in a solvent reservoir and the solvent moves up the plate by

capillary action. When the solvent front reaches the other edge of the stationary phase, the plate is removed from the solvent reservoir. The separated spots are visualized with ultraviolet light or by placing the plate in iodine vapor. The different components in the mixture move up the plate at different rates as a result of differences in their partitioning behavior between the mobile liquid phase and the stationary phase.

Titrimetry Kits

Thin-layer chromatography consists of a stationary phase immobilized on a glass or plastic plate and a solvent. The sample, either liquid or dissolved in a volatile solvent (n-butanol and cellulose acetate), is deposited as a spot on the stationary phase. The constituents of a sample can be identified by simultaneously running standards with the unknown. One edge of the plate is then placed in a solvent reservoir and the solvent moves up the plate by capillary action. When the solvent front reaches the other edge of the stationary phase, the plate is removed from the solvent reservoir. The separated spots are visualized with ultraviolet light or by placing the plate in iodine vapor. The different components in the mixture move up the plate at different rates as a result of differences in their partitioning behavior between the mobile liquid phase and the stationary phase.

Toxicity Tests

Toxicity tests use specific aquatic and terrestrial organisms or microorganisms to measure biological response to specific contaminants or mixtures of contaminants. The toxicity test consists of luminescent microorganisms that emit light as a normal consequence of respiration and a temperature controlled illuminometer that reads the bacterial light output. Chemicals or chemical mixtures that are toxic to the bacteria cause a reduction in light output proportional to the strength of the toxin. A computer is linked to the system to provide data processing and storage capabilities.

Ultraviolet Fluorescence

Ultraviolet (UV) fluorescence has been used in a number of applications for field screening including: (1) semi-quantitative analysis of solvent extracted PAHs, (2) in conjunction with fiber optic sensors, and (3) as a surface contamination detector, in which a non-fluorescing substance sprayed on the ground surface reacts chemically with the contaminant of interest to form a substance that fluoresces with UV excitation.

Ultraviolet Visible Spectrophotometry

Ultraviolet Visible Spectrophotometry is used to detect transition metal ions, highly conjugated organic compounds, and biological macromolecules. It encompasses a number of techniques involving measurement of the absorption spectra of narrow band widths of radiation. Visible spectrometry covers the range of 380 to 780 nano-meters (nm) and uses tungsten lamps as the radiation source, glass or quartz prisms in the monochromators, and photo-multiplier cells as the detector. UV spectrometers cover the region from 200 to 400 nm and usually use a hydrogen lamp as a radiation source, a quartz prism in the monochromator, and a photo-multiplier tube as the detector.

Waterloo Advanced Profiling System (direct sensing)

The Waterloo Advanced Profiling Systems (WaterlooAPS) is a direct-push groundwater sampling technology used to collect discrete interval samples in a continuous vertical profile. In addition to groundwater sample collection, the system provides measurements of other physiochemical data, including a continuous real-time read-out of an Index of Hydraulic Conductivity (Ik), hydraulic head, specific conductance (SC), dissolved oxygen (DO), pH, oxidation-reduction potential (ORP), and temperature. The stainless-steel profiling tip has 16 ports arranged in four rows with an open sampling interval approximately 2.5 inches in length. Port screens can be changed to reduce turbidity or optimize sampling productivity. To minimize sorption of contaminants to system materials, stainless steel tubing conveys groundwater from the profiling tip to the sample collection apparatus at the surface. A sacrificial profiling tip allows retraction grouting of completed profiling boreholes. Groundwater samples are collected using either a peristaltic or a downhole nitrogen gas-drive pump, depending on depth to the water table.

Samples are collected directly into glass, zero-headspace, in-line sample containers that prevents sample contact with system materials and ambient air. The containers are located on the suction side of the peristaltic pump to prevent contact with pump head tubing.

D.3 What Technologies May be Used to Treat Contaminants at Brownfields Sites?

Table D-3 lists technologies used to treat contaminant groups typically found at Brownfields sites followed by short descriptions of each treatment technology.

Table D-3: Treatment Technologies Used at Brownfields Sites

Treatment Technology	Halogenated VOCs	Nonhalogenated VOCs	Halogenated SVOCs	Nonhalogenated SVOCs	Fuels	Metals and metalloids	Explosives
Air Sparging	G	G			G		
Bioremediation	G/S	G/S	G/S	G/S	G/S		G/S
Chemical Treatment	G/S	G/S	G/S	G/S	G/S	G/S	G/S
Electrokinetics	G/S	G/S	G/S	G/S		G/S	
Flushing	G/S	G/S	G/S	G/S	G/S	G/S	
Incineration	S	S	S	S	S		S
In-Well Air Stripping	G	G					
Mechanical Soil Aeration	S						
Multi-Phase Extraction	G/S	G/S	G/S	G/S	G/S		
Nanoremediation	G/S	G/S	G/S	G/S	G/S	G/S	G/S
Open Burn/Open Detonation							S
Permeable Reactive Barrier	G	G	G	G	G	G	G
Physical Separation			S	S		S	
Phytoremediation	G/S	G/S	G/S	G/S	G/S	G/S	G/S
Pump and Treat	G	G	G	G	G	G	G
Soil Amendments	S		S	S	S	S	S
Soil Vapor Extraction	S	S			S		
Soil Washing	S	S	S	S	S	S	S
Solidification/Stabilization	S	S	S	S	S	S	S
Solvent Extraction	S	S	S	S	S	S	S
Thermal Desorption	S	S	S	S	S		S
Thermal Treatment (in situ)	G/S	G/S	G/S	G/S	G/S		
Vitrification	S	S	S	S	S	S	

G - Groundwater, leachate, and surface water

S - Soils, sediments, and sludges

Air Sparging
Air sparging involves injection of air or oxygen into a contaminated aquifer. Injected air traverses horizontally and vertically in channels through the soil column, creating an underground stripper that removes volatile and semivolatile organic contaminants by volatilization. The injected air helps to flush the contaminants into the unsaturated zone. Soil Vapor Extraction (SVE) usually is implemented in conjunction with air sparging to remove the generated vapor-phase contamination from the vadose zone. Oxygen added to the contaminated groundwater and vadose zone soils also can enhance biodegradation of contaminants below and above the water table.

Bioremediation
Bioremediation involves use of microorganisms to degrade organic contaminants in soil, sludge, solids, and groundwater either in situ or ex situ. It can also be used to make metals or metalloids less toxic or mobile. When organic contaminants are being treated, the microorganisms break down contaminants by using them as a food source or by cometabolizing them with a food source. Aerobic processes require an oxygen source, and the end products typically are carbon dioxide and water. Anaerobic processes are conducted in the absence of oxygen, and the end products can include methane, hydrogen gas, sulfide, elemental sulfur, and nitrogen gas. Bioremediation techniques stimulate and create a favorable environment for microorganisms to grow and use contaminants as a food and energy source or to cometabolize them. Generally, this process involves providing some combination of oxygen (for aerobic processes only), food, nutrients, and moisture and controlling the temperature and pH. Microorganisms that have been adapted for degradation of specific contaminants are sometimes added to enhance the process. The process for treatment of metals and metalloids involves biological activity that promotes formation of less toxic or mobile species by creating ambient conditions that will cause these species to form or by acting directly on the contaminant. The treatment may result in oxidation, reduction, precipitation, coprecipitation, or another transformation of the contaminant.

Chemical Treatment
Chemical treatment, also known as chemical reduction/oxidation (redox), typically involves redox reactions that chemically convert hazardous contaminants into compounds that are nonhazardous, less toxic, more stable, less mobile, or inert. Redox reactions involve the transfer of electrons from one compound to another. Specifically, one reactant is oxidized (loses electrons) and one reactant is reduced (gains electrons). The oxidizing agents used for treatment of hazardous contaminants in soil include ozone, hydrogen peroxide, hypochlorites, potassium permanganate, Fenton's reagent (hydrogen peroxide and iron), chlorine, and chlorine dioxide. This method may be applied in situ or ex situ to soils, sludges, sediments, and other solids, and may also be applied to groundwater in situ or ex situ chemical treatment using pump and treat technology. Pump and treat chemical treatment may also include use of UV light in a process known as UV oxidation.

Electrokinetics
Electrokinetics is based on the theory that a low-density current will mobilize contaminants in the form of charged species. A current passed between electrodes is intended to cause aqueous media, ions, and particulates to move through soil, waste, and water. Contaminants arriving at the electrodes can be removed by means of electroplating or electrodeposition, precipitation or coprecipitation, adsorption, complexing with ion exchange resins, or pumping water (or other fluid) near the electrodes.

Flushing
For flushing, a solution of water, surfactants, or cosolvents is applied to soil or injected into the subsurface to treat contaminated soil or groundwater. When soil is treated, the injection is often designed to raise the water table into the contaminated soil zone. Injected water and treatment agents are recovered together with flushed contaminants.

Incineration
Both on-site and off-site incineration involves use of high temperatures (870 to 1,200°C or 1,600 to 2,200°F) to volatilize and combust (in the presence of oxygen) organic compounds in hazardous wastes. Auxiliary fuels are often used to initiate and sustain combustion. The destruction and removal efficiency of properly operated incinerators exceeds the 99.99 percent requirement for hazardous waste and can meet the 99.9999 percent requirement for PCBs and dioxins. Off-gases and combustion residuals generally require treatment. On-site incineration is typically a transportable unit. Waste is transported to a central facility for off-site incineration.

In-Well Air Stripping
For in-well air stripping, air is injected into a double-screened well, causing the VOCs in the contaminated groundwater to be transferred from the dissolved phase to the vapor phase in air bubbles. As the air bubbles rise to the surface of the water, the vapors are drawn off and treated by an SVE system.

Mechanical Soil Aeration
Mechanical soil aeration involves agitation of contaminated soil using tilling or other means to volatilize contaminants.

Multi-Phase Extraction
Multi-phase extraction involves use of a vacuum system to remove various combinations of contaminated groundwater, separate-phase petroleum product, and vapors from the subsurface. The system typically lowers the water table around a well, exposing more of the formation. Contaminants in the newly exposed vadose zone are then accessible for vapor extraction. Once above ground, the extracted vapors or liquid-phase organics and groundwater are separated and treated.

Nanoremediation
Nanoremediation is a relatively new technology for environmental remediation. “Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications” (National Nanotechnology Initiative [NNI] 2008). Nanoparticles can be highly reactive because of their large surface area to volume ratio and the presence of a greater number of reactive sites. These features allows for increased contact with contaminants, thereby resulting in rapid reduction of contaminant concentrations.

Open Burn/Open Detonation
Open burn (OB) and open detonation (OD) operations are conducted to destroy excess, obsolete, or unserviceable (EOU) munitions and other items containing explosives, propellants, and other energetic materials. In OB operations, materials are destroyed by self-sustained combustion, which is ignited by an external source, such as a flame, heat, or a detonation wave. In OD operations, materials are destroyed by detonation, which generally is initiated by an energetic charge.

Permeable Reactive Barrier
Permeable reactive barriers (PRB), also known as passive treatment walls, are installed across the flow path of a contaminated groundwater plume, allowing the water portion of the plume to flow through the wall. These barriers allow passage of water while prohibiting movement of contaminants by means of treatment agents within the wall such as zero-valent metals (usually zero-valent iron), chelators, sorbents, compost, and microbes. The contaminants are either degraded or retained in a concentrated form by the barrier material, which may need to be replaced periodically.

Physical Separation

Physical separation processes use physical properties to separate contaminated and uncontaminated media or to separate different types of media. For example, different-sized sieves and screens can be used to separate contaminated soil from relatively uncontaminated debris. Another application of physical separation is dewatering sediments or sludge.

Phytoremediation

Phytoremediation is a process in which plants are used to remove, transfer, stabilize, or destroy contaminants in soil, sediment, or groundwater. The mechanisms of phytoremediation include enhanced rhizosphere biodegradation (which takes place in soil or groundwater immediately around plant roots), phytoextraction (also known as phytoaccumulation, the uptake of contaminants by plant roots and the translocation and accumulation of contaminants into plant shoots and leaves), phytodegradation (metabolism of contaminants within plant tissues), and phytostabilization (production of chemical compounds by plants to immobilize contaminants at the interface of roots and soil). Phytoremediation applies to all biological, chemical, and physical processes that are influenced by plants (including the rhizosphere) and that aid in the cleanup of contaminated substances. Phytoremediation may be applied in situ or ex situ to soils, sludges, sediments, other solids, or groundwater.

Pump and Treat

Pump and treat involves extraction of groundwater from an aquifer and treatment of the water above the ground. The extraction step is usually conducted by pumping groundwater from a well or trench. The treatment step can involve a variety of technologies such as adsorption, air stripping, bioremediation, chemical treatment, filtration, ion exchange, metal precipitation, and membrane filtration.

Soil Amendments

Many soils, particularly those found in urban, industrial, mining, and other disturbed areas, suffer from a range of physical, chemical, and biological limitations. They include soil toxicity, too high or too low pH, lack of sufficient organic matter, reduced water-holding capacity, reduced microbial communities, and compaction. Appropriate soil amendments may be inorganic (such as liming materials), organic (for example, composts) or mixtures (such as lime-stabilized biosolids). When specified and applied properly, these beneficial soil amendments limit many of the exposure pathways and reduce soil phytotoxicity. Soil amendments also can restore appropriate soil conditions for plant growth by balancing pH, adding organic matter, restoring soil microbial activity, increasing moisture retention, and reducing compaction. Soil amendments can reduce the bioavailability of a wide range of contaminants while simultaneously enhancing success of revegetation and, thereby, protecting against off-site movement of contaminants by wind and water. As such, they can be used in situations ranging from time-critical contaminant removal actions to long-term ecological revitalization projects. Using these residual materials (industrial byproducts) offers the potential for significant cost savings compared with traditional alternatives. In addition, land revitalization using soil amendments has significant ecological benefits, including benefits for the hydrosphere and atmosphere.

Soil Vapor Extraction

Soil vapor extraction (SVE) is used to remediate unsaturated (vadose) zone soil. A vacuum is applied to the soil in order to induce a controlled flow of air and remove volatile and some semivolatile organic contaminants from the soil. SVE usually is performed in situ; however, in some cases, it can be used as an ex situ technology.

Soil Washing

For Soil washing, contaminants sorbed onto fine soil particles are separated from bulk soil in a water-based system based on particle size. The wash water may be augmented with a basic leaching agent, surfactant, or chelating agent or by adjusting pH to help remove contaminants. Soils and wash water are mixed ex situ in a tank or other treatment unit. The wash water and various soil fractions are usually separated by means of gravity settling.

Solidification/Stabilization
Solidification/stabilization (S/S) reduces the mobility of hazardous substances and contaminants in the environment through both physical and chemical means. The S/S process physically binds or encloses contaminants within a stabilized mass. S/S can be performed both ex situ and in situ. Ex situ S/S requires excavation of the material to be treated, and the treated material must be disposed of. In situ S/S involves use of auger or caisson systems and injector head systems to add binders to contaminated soil or waste without excavation, and the treated material is left in place.

Solvent Extraction
Solvent extraction involves use of an organic solvent as an extractant to separate contaminants from soil. The organic solvent is mixed with contaminated soil in an extraction unit. The extracted solution is then passed through a separator, where the contaminants and extractant are separated from the soil.

Thermal Desorption
For thermal desorption, wastes are heated so that organic contaminants and water volatilize. Typically, a carrier gas or vacuum system transports the volatilized organic compounds and water to a gas treatment system, usually a thermal oxidation or recovery system. Based on the operating temperature of the desorber, thermal desorption processes can be categorized in two groups: high-temperature thermal desorption (320 to 560°C or 600 to 1,000°F) and low-temperature thermal desorption (90 to 320°C or 200 to 600°F). Thermal desorption is an ex situ treatment process.

Thermal Treatment (in situ)
In situ thermal treatment is a treatment process that uses heat to facilitate contaminant extraction through volatilization and other mechanisms or to destroy contaminants in situ. Volatilized contaminants are typically removed from the vadose zone using SVE. Specific types of in situ thermal treatment include conductive heating, electrical resistive heating (ERH), radio frequency heating (RFH), hot air injection, hot water injection, and steam-enhanced extraction. In situ thermal treatment is usually applied to a contaminated source area but may also be applied to a groundwater plume.

Vitrification
Vitrification involves use of an electric current to melt contaminated soil at elevated temperatures (1,600 to 2,000°C or 2,900 to 3,650°F). When it cools, the vitrification product is a chemically stable, leach-resistant glass and crystalline material similar to obsidian or basalt rock. The high-temperature component of the process destroys or removes organic materials. Radionuclides and heavy metals are retained within the vitrified product. Vitrification may be conducted in situ or ex situ.

D.4 Types of Contaminant Groups

While a wide variety of contaminants may be present at Brownfields sites, the following are the more common contaminant groups found at these sites. The seven common contaminant groups used in Tables D-1 to D-3 are described below.

Halogenated VOCs

VOCs are hydrocarbon compounds that evaporate readily at room temperature. A halogen (fluorine, chlorine, bromine, or iodine) is attached to a halogenated VOC. Locations where halogenated VOCs may be found include burn pits, chemical manufacturing plants and disposal areas, contaminated marine sediments, disposal wells and leach fields, electroplating and metal finishing shops, firefighting training areas, hangars and aircraft maintenance areas, landfills and burial pits, leaking storage tanks, radioactive and mixed waste disposal areas, oxidation ponds and lagoons, dry cleaning shops, grain storage sites, paint stripping and spray booth areas, pesticide and herbicide mixing areas, solvent degreasing areas, surface impoundments, and vehicle maintenance areas.

Nonhalogenated VOCs

No halogen (fluorine, chlorine, bromine, or iodine) is attached to a nonhalogenated VOC. Locations where nonhalogenated VOCs may be found include burn pits, chemical manufacturing plants and disposal areas, contaminated marine sediments, disposal wells and leach fields, electroplating and metal finishing shops, firefighting training areas, hangars and aircraft maintenance areas, landfills and burial pits, leaking storage tanks, radioactive and mixed waste disposal areas, oxidation ponds and lagoons, paint stripping and spray booth areas, pesticide and herbicide mixing areas, solvent degreasing areas, surface impoundments, and vehicle maintenance areas.

Halogenated SVOCs

A halogen (fluorine, chlorine, bromine, or iodine) is attached to halogenated SVOCs are hydrocarbon compounds with boiling points greater than 200ºC. Locations where halogenated SVOCs may be found include burn pits and other combustion sources, chemical manufacturing plants and disposal areas, contaminated marine sediments, disposal wells and leach fields, electroplating and metal finishing shops, firefighting training areas, hangars and aircraft maintenance areas, landfills and burial pits, leaking storage tanks, radioactive and mixed waste disposal areas, oxidation ponds and lagoons, dry cleaning shops, grain storage sites, pesticide and herbicide mixing areas, solvent degreasing areas, surface impoundments, vehicle maintenance areas, and wood preservation sites. Pesticides are a subgroup of halogenated SVOCs.

Nonhalogenated SVOCs

No halogen (fluorine, chlorine, bromine, or iodine) is attached to a nonhalogenated SVOC. Locations where nonhalogenated SVOCs may be found include burn pits, chemical manufacturing plants and disposal areas, contaminated marine sediments, disposal wells and leach fields, electroplating and metal finishing shops, firefighting training areas, hangars and aircraft maintenance areas, landfills and burial pits, leaking storage tanks, radioactive and mixed waste disposal areas, oxidation ponds and lagoons, pesticide and herbicide mixing areas, solvent degreasing areas, surface impoundments, and vehicle maintenance areas, and wood preservation sites.

Fuels

Fuels are a general class of chemicals created by refining and manufacturing petroleum or natural gas for use in combustion processes to generate heat or other energy. Fuels include nonhalogenated VOCs, nonhalogenated SVOCs, or both. Sites where fuel contamination may be found include aircraft, storage and service areas, burn pits, chemical disposal areas, contaminated marine sediments, disposal wells and leach fields, firefighting training areas, hangars and aircraft maintenance areas, landfills and burial pits, leaking storage tanks, solvent degreasing areas, surface impoundments, and vehicle maintenance areas.

Metals and metalloids

Metals are one of the three groups of elements distinguished by their ionization and bonding properties, along with metalloids and nonmetals. Metals have certain characteristic physical properties: they are usually shiny, have a high density, are ductile and malleable, usually have a high melting point, are usually hard, and conduct electricity and heat well. Metalloids have properties that are intermediate between those of metals and nonmetals. There is no unique way of distinguishing a metalloid from a true metal, but the most common way is that metalloids are usually semiconductors rather than conductors. Locations where metals and metalloids may be found include artillery and small arms impact areas, battery disposal areas, burn pits, chemical disposal areas, contaminated marine sediments, disposal wells and leach fields, electroplating and metal finishing shops, firefighting training areas, landfills and burial pits, leaking storage tanks, radioactive and mixed waste disposal areas, oxidation ponds and lagoons, paint stripping and spray booth areas, sand blasting areas, surface impoundments, and vehicle maintenance areas.

Explosives

Most commonly, artificial explosives are chemical explosives manufactured for use as explosives and propellants. Sites where explosive contaminants may be found include artillery impact areas, contaminated marine sediments, disposal wells, leach fields, landfills, burial pits, and TNT washout lagoons.