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07/27/2009 09:31 AM

To RONALD MURAWSKI
cc Diana Embil
bcc
Subject Tremont, SURF White Paper

Ron: Please find attached a recently issued white paper regarding sustainable remediation. RESA requests that this be included in as an addendum to our position statement for review by the NRRB. Thanks, and please do not hesitate to contact me with any questions.

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Sustainable Remediation White Paper—Integrating Sustainable Principles, Practices, and Metrics Into Remediation Projects

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Paul W. Hadley

1.0 INTRODUCTION

The remediation industry was born in the late 1970s, following a steady stream of highly publicized discoveries of toxic chemicals in landfills, drinking water, and even neighborhoods. The government responded to these discoveries of environmental contamination. Environmental laws were passed at the state and national level, and programs were created within environmental regulatory agencies to oversee and sometimes fund the cleanups. Industry and consultants kept pace by hiring staff, building programs, and initiating cleanups. The remediation industry was off at a sprint before it had learned to crawl.

With the public demand for swift and sometimes immediate cleanups, responsible parties and the remediation industry invested heavily in energy-intensive engineered projects, such as groundwater pump-and-treat systems, soil excavation and off-site disposal, incineration, and thermal treatment. The public's attitude was that no cleanup could be initiated soon enough or implemented fast enough.

While such energy-intensive remediation systems are well intended, they generally have not achieved acceptable cleanup levels (National Research Council [NRC], 2005). These energy-intensive engineered remedies frequently cannot overcome the basic technical limitations encountered when recovering contaminants from the environment once the contaminants are widespread and dilute. As a result, most engineered groundwater remediation systems reach a certain concentration and go no further regardless of the energy expended. The concentration that can be reached is often far higher than the cleanup level.

Within the last ten years, a growing body of information suggests that global climate change can be correlated with fossil fuel use and carbon dioxide releases into the atmosphere. As members of the broader environmental industry, remediation experts are well aware of this concern and have firsthand knowledge of the potential contribution of energy-intensive remediation systems to global climate change. For example, at one remediation project in New Jersey, it was estimated that the difference between two proposed remedies could be as high as 2 percent of the annual greenhouse gas emissions

Published online in Wiley Interscience (www.interscience.wiley.com). DOI: 10.1002/rem.20210

for the entire state (Ellis et al., 2008). Similar to other industries, the remediation industry uses energy, consumes raw materials, and otherwise contributes to humankind's carbon footprint.

1.1 Background

Most segments of industrialized society are rethinking how behavior, reliance on technology, and consumption of energy impact the environment. Society is looking for ways to minimize these impacts, or avoid them altogether, so that human activity can become more sustainable.

The mission of SURF is to establish a framework that incorporates sustainable concepts throughout the remedial action process while continuing to provide long-term protection of human health and the environment and achieving public and regulatory acceptance.

In 2006, a group of remediation professionals banded together to contribute to this same rethinking process for the remediation industry. They formed an organization that came to be known as the Sustainable Remediation Forum (SURF). The mission of SURF is to establish a framework that incorporates sustainable concepts throughout the remedial action process while continuing to provide long-term protection of human health and the environment and achieving public and regulatory acceptance. First and foremost, SURF's vision of sustainable remediation always includes fulfilling obligations to remediate sites so that they are fully protective of human health and the environment.

In this document, sustainable remediation is broadly defined as a remedy or combination of remedies whose net benefit on human health and the environment is maximized through the judicious use of limited resources. To accomplish this, SURF embraces sustainable approaches to remediation that provide a net benefit to the environment. To the extent possible, these approaches:

1. Minimize or eliminate energy consumption or the consumption of other natural resources;
2. Reduce or eliminate releases to the environment, especially to the air;
3. Harness or mimic a natural process;
4. Result in the reuse or recycling of land or otherwise undesirable materials; and/or
5. Encourage the use of remedial technologies that permanently destroy contaminants.

SURF recognizes that sustainable remediation is unique in that it addresses the current and future practices of an industry that is cleaning up those parts of the environment impacted by poor industrial practices of the past. In addition, sustainability concepts have the potential to minimize the deleterious environmental side effects of remediation. However, SURF believes that the true benefit of sustainability is in guiding remediation professionals to make better—and eventually much better—decisions.

A schematic of the evolution and maturation of the remediation industry is depicted in Exhibit 1-1. Although somewhat speculative in nature, this exhibit shows the logical stages of evolution and maturation of the remediation industry. Many of these stages are now more tangible and apparent than ever. SURF views sustainable remediation as a logical component in the maturation of the remediation industry.

Many organizations at the state and federal levels are working to increase the use of sustainable practices in remediation. In addition, SURF is working to raise the national and international awareness and discussion of sustainable remediation. Members have written articles, made presentations, served on panels, and worked together wherever possible to communicate about sustainable remediation. SURF believed that the logical

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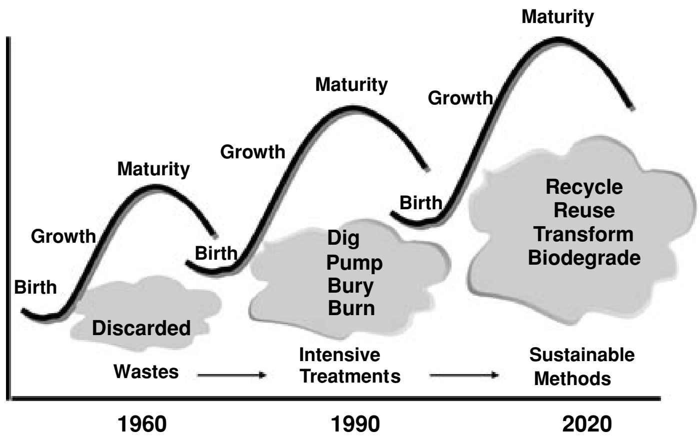

Exhibit 1-1. Evolution of the thinking about wastes and cleanups: Transforming our thought process

next step was to collect and document the members' cumulative experiences and beliefs as a way of furthering the cause: to include sustainability principles and practices in remediation projects. Thus, SURF began preparing this document in late 2007.

1.2 Purpose

SURF initiated this document in late 2007 to collect, clarify, and communicate the thoughts and experiences of the SURF membership on the incorporation of sustainability concepts and principles into remediation. As such, the document is a platform from which individual SURF members can share the collective thinking of the group with others. Because sustainability is a relatively new concept in most segments of industrialized society and even newer to the remediation industry, this document does not claim to contain all of the answers. More importantly, it is the intent of SURF to identify the right questions in this document.

1.3 Scope

This document evaluates the current status of sustainable remediation practices, identifies the various perspectives advocating for or against sustainable remediation, and considers how sustainable remediation practices improve the status quo.

Please note that SURF is composed primarily of members located in the United States, some of whom work for global companies. As a consequence, the recommendations contained in this document are principally focused on changes within the United States, although these recommendations could apply to other countries.

SURF defines sustainable remediation practices not only as those practices that reduce global impacts (e.g., greenhouse gases), but also as those that reduce local atmospheric effects, potential impacts on worker and community safety, and/or the consumption of natural energy resources (beyond fuel consumption) that might be attributable to remediation activities. In this way, this document focuses on remediation industry activities that most directly impact the environment. Although the "triple bottom line" of the environment, the economy, and social interests is discussed in this document (see

Section 5.1), SURF members are mostly concerned with finding scientific and engineering approaches and alternatives that reduce the secondary (and heretofore largely unaccounted for) impacts of remediation on the environment. This focus fits the collective expertise of SURF members and constitutes a significant contribution on its own.

This document presents evidence of the benefits of sustainable remediation and provides examples where sustainable metrics were incorporated into remedy selection, design, and implementation. Because this document is based on the experiences of SURF members, it addresses cleanup at sites with soil and/or groundwater contamination that are regulated under state and federal cleanup programs. Although sustainable practices are germane to a wide range of other types of cleanup projects (e.g., those sites involving unexploded ordnance, building decontamination, biological threats, or radionuclide cleanup), these projects are not the focus of this document.

During the development of this document, SURF identified the following four special topics that apply to most, if not all, remediation projects: the responsible application of sustainable practices, risk assessment, source treatment or removal, and the standard unit of remediation.

1.4 Special Topics

During the development of this document, SURF identified the following four special topics that apply to most, if not all, remediation projects: the responsible application of sustainable practices, risk assessment, source treatment or removal, and the standard unit of remediation. While these topics are not typical of the content generally discussed at the beginning of a document, they apply to most, if not all, remediation projects and, therefore, influence virtually every section of this document.

1.4.1 Using Sustainability Responsibly

One fear of some regulators and members of the public is that sustainability will become an excuse for doing nothing or that all remediation projects will become some version of natural attenuation. While SURF believes that considering sustainability in all facets of remediation could substantially improve the remediation industry, SURF recognizes that the concept of sustainable remediation could potentially be abused or at least be viewed as being abused. This is because some sustainable remedies may also have a lower cost than energy-intensive solutions. It is important for the remediation industry to develop standards and train personnel so that everyone will recognize and avoid potential misuses of sustainability in remediation. This issue is addressed further in Sections 4.0 and 5.2.

1.4.2 Risk Assessment

Risk assessment is applied in some form or another at virtually every large or complex remediation site. SURF has watched risk assessment evolve from some very simplistic and overly conservative calculations of risk to sophisticated multimedia computer models that provide highly precise (although highly uncertain) estimates of risk and hazard. For over 25 years, a significant amount of experience has been gained about the use and utility of risk assessment during remediation.

As the use of risk assessment for the remediation of waste sites has evolved and progressed, the following has become increasingly apparent: the risks associated with many sites are relatively small, pertain to a small population, and/or are speculative to hypothetical in nature. It has also become apparent to SURF that a far greater risk of significant injury and even fatality exists for remediation workers and impacted

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community (e.g., truck accidents on the open road). These risks are not given proper consideration in remediation decisions. This concern is further discussed in Section 4.2.5.

1.4.3 Source Treatment or Removal

Although many believe that the treatment or removal of a contamination source is immediately beneficial in every instance, this may not always be the case, particularly for sources that contain dense nonaqueous-phase liquids (DNAPLs), such as trichloroethene and tetrachloroethene. When source treatment has been attempted in these cases, the results have largely been disappointing (NRC, 2005). In one survey (Geosyntec Consultants, 2004), it was apparent that in the rush to treat source zones, basic steps (e.g., identifying measurable or tangible objectives) were not performed. In large measure, these disappointing outcomes can be attributed to pressure to accomplish cleanup in the absence of sound scientific and engineering practices.

This "rush to remediation" has often been encouraged by regulatory policy, regulatory culture, statutes, public pressure, and the unwillingness of all parties to recognize the limitations of their own approaches. As a result, repeated attempts at source remediation are not uncommon—each requiring additional resources and energy and each having additional negative environmental consequences without achieving the treatment objectives. This subject is discussed in detail in Section 4.2.4.

1.4.4 The Unit of Remediation

One uncertainty that surfaced repeatedly during SURF meetings was comparing the relative sustainability of remedies from site to site. Experts in life-cycle analysis suggest that, in order to make defensible comparisons, the remediation profession needs to identify the fundamental unit of remediation. For example, in a life-cycle assessment (LCA) of beverage containers, the practitioner would strive to find a common denominator among types of containers. Thus, for plastic, glass, or aluminum (typical choices for containing beverages), the LCA might estimate energy and environmental burdens per ounce of beverage contained. Thus, a direct comparison among containers is possible.

At present, it is difficult to imagine how vastly different remedial technologies can be compared so directly or how different site applications can be compared directly. There is no apparent simple way of constructing a common denominator for these various remedial approaches.

At present, it is difficult to imagine how vastly different remedial technologies can be compared so directly or how different site applications can be compared directly. There is no apparent simple way of constructing a common denominator for these various remedial approaches. At the time of this publication, SURF had not yet reached consensus on how to best define a unit of remediation, but agreed that resolving this issue would substantially aid in making better and more sustainable remediation decisions.

1.5 Developing This Document

Working groups within SURF wrote the major sections of this document, with each group serving under the general direction of a volunteer facilitator for each major section. The working groups first developed outlines that were peer reviewed by SURF members. Overlaps and unaddressed issues were identified by the facilitators and then assigned to a specific workgroup. As work progressed, the sections were made available for peer review. The resulting suggestions were discussed in SURF meeting working groups, after which each workgroup progressed to the next stage of writing. Consensus was sought on all issues. Where consensus could not be reached, the differing views are presented in this document. At all times, discussions about the document were open to SURF meeting participants. Records of SURF meetings, including discussions about this document, are posted on www.sustainableremediation.org.

1.6 Acknowledgments

Members of SURF especially want to acknowledge the efforts of two people, without whom this document would never have been created. The first is Kathy O. Adams (Writing Unlimited), whose heroic editing efforts turned our purple prose into intelligent and legible literature that spoke with a single voice. The second person is Mike Rominger, who facilitated SURF meetings with fairness and ease, enabling members to work together and make great progress.

David E. Ellis, PhD, leads the science and technology program of DuPont's Corporate Remediation Group. He founded and chaired several international consortia to develop safe and effective environmental treatments and currently chairs a multinational government/industry consortium based in the United Kingdom. He founded and chairs the Sustainable Remediation Forum and leads DuPont's internal remediation sustainability group. He was an active member of several US EPA and U.S. National Research Council Committees examining environmental cleanups and taught extensively on behalf of several U.S. government groups, the U.S. National Science Foundation, and NATO. He earned his PhD at Yale University, was a member of the research faculty at the University of Chicago, and has been with DuPont since 1978.

Paul W. Hadley is a senior hazardous substances engineer with California's Department of Toxic Substances Control. He has been active in the Interstate Technology and Regulatory Council since the organization's inception and has participated in document development and training efforts concerning natural attenuation and *in situ* bioremediation of chlorinated solvents. Over the last 20 years, he has authored numerous publications on topics related to risk and remediation.

2.0 DESCRIPTION AND CURRENT STATUS OF SUSTAINABLE REMEDIATION

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Raymond J. Vaské

As stated previously, within the context of this document, sustainable remediation is defined as a remedy or combination of remedies whose net benefit on human health and the environment is maximized through the judicious use of limited resources. As presented in the survey results discussed in Section 2.3.1, there is considerable debate among stakeholders regarding what is sustainable and what is judicious. However, related "wise-use" concepts are garnering the interest of remediation stakeholders who are willing to identify and evaluate net benefit solutions to complex remediation challenges on a project-by-project basis. In this section, the remediation stakeholders are identified, along with the current and developing institutional frameworks that are available to interested practitioners of environmental remediation. Although most of this section focuses on the United States, information is included about activities occurring in all habitable continents (with one exception). Very little information exists about sustainable remediation efforts in Africa; therefore, this continent is not discussed.

2.1 Environmental Remediation Stakeholders and Drivers

As stated previously, the selection of remediation technologies in the United States historically has been driven by health protection criteria, cost, efficacy, technical practicability, and regulatory acceptance. However, stakeholders have learned that these remediation drivers do not necessarily result in a clean or closed site on a timely basis and, depending on the perspective of the stakeholder, could represent a net environmental loss to the larger community. Accordingly, stakeholders have realized that the selection of remediation technologies should also evaluate the probability with which these and future projects will have a net environmental and societal benefit.

Generally, the stakeholders in the remediation process belong to one of the following four groups: site owners, regulatory entities, the public, and industry service providers. The boundaries between these groups are, at times, indistinct; however, each is represented in one form or another as a stakeholder in the process.

While sustainability may not mean the same thing to all of these groups, it is through an understanding of the perspectives of each of these groups that the stakeholders can come to a mutually beneficial, project-specific definition of sustainability. The project-specific definition of sustainability can be established through multivariable decision analysis and effective stakeholder communication or negotiation. Although the stakeholders must evaluate the drivers for each potentially applicable remediation technology (e.g., efficacy, cost, regulatory acceptance), they must also evaluate the drivers of sustainable practices. Net environmental benefit is one such driver and is defined herein as remedies resulting in effective cleanups that maximize environmental benefits (e.g., the reduction of contaminant and energy footprints of site remediation) while protecting human health and the environment. Ideally, the negotiation process will result in a sustainable approach and acceptable agreement that incorporates site conditions; local, state, and/or federal requirements; responsible parties; and the community stakeholders.

The subsections that follow describe the various remediation stakeholders and their potential motivations with regard to the employment of sustainable principles to the practice of environmental remediation. Through open and thorough consideration of the understandings and attitudes of each of these stakeholder groups, a project-specific set of sustainability drivers can be developed and incorporated into remedial programs.

2.1.1 Site Owners

Site owners can consist of the property owner or operator or can be represented by another organization that accepts responsibility for the property (in the case of abandoned or formerly owned sites) or by those representing the property owner (e.g., environmental consultants and engineers). Less frequently, the property owner is represented by government agencies (e.g., municipalities). Site owners are those individuals who have accepted administrative and/or financial responsibility for the environmental liability requiring remediation.

The site owner considers sustainability issues based on a variety of drivers, including, but not limited to, social responsibility, a goal to follow overarching requirements (e.g., corporate policy), and a desire to implement a sustainable remedial response (including resource consumption and cost) that outweighs the consequences of otherwise insufficient responses.

In step with the national and international momentum to identify sustainable solutions to resource and energy issues, regulatory entities are beginning to include a variety of sustainability metrics in the evaluation of remedial alternatives, remedial implementations, and remedial endpoints.

2.1.2 Regulatory Entities

Regulatory involvement can include federal agencies, tribal organizations, state agencies, and local agencies to guide the scope, schedule, and endpoints of the remediation process. Regulators are responsible for enforcing applicable regulations from a wide variety of programs, which, in the United States, may include the Resource Conservation and Recovery Act (RCRA); the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); the Clean Water Act (CWA); the Toxic Substances Control Act (TSCA); and other federal or state programs, which include a variety of voluntary cleanup programs.

Generally speaking, regulatory stakeholders are responsible for assuring that the remedial process is consistent with legislative requirements and agency policies and is protective of human health and the environment. Because of this explicit responsibility for protection of human health, the stakeholder representing the broader public interest can be included in the regulatory entity category.

In step with the national and international momentum to identify sustainable solutions to resource and energy issues, regulatory entities are beginning to include a variety of sustainability metrics in the evaluation of remedial alternatives, remedial implementations, and remedial endpoints. Because of the growing number of general sustainability programs and activities implemented within many countries, including the United States, there is increasing pressure for the regulators of contaminated sites undergoing environmental remediation to consider net impacts as part of their criteria of what is protective of human health and the environment.

2.1.3 Public

Public involvement in the remedial process has evolved substantially in the almost 40 years that have passed since the creation of the U.S. Environmental Protection Agency (US EPA). Although the CWA, RCRA, CERCLA, and other programs have always included some level of public participation, it has only been since the late 1980s through 1990s that interactive inclusion of the public into the resolution of environmental issues has become

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widespread. Much of the increase in public participation has been instigated by the evolving concept of environmental justice and as a response to "not in my backyard" sentiments.

As mentioned previously, the public's role as a stakeholder in remediation processes can overlap with the role of the regulatory entities to enforce the protection of human health and the environment. With regard to sustainability, the public's role has expanded to include participation in discussions regarding the remedy's impacts on community livability and vitality, end uses of remediated areas, and residual environmental impacts and their effects on property values and quality of life.

2.1.4 Industry Service Providers

Industry service providers can include environmental consulting firms, specialized remediation companies, and related service providers. Industry service providers typically assist with the development of the scope, schedule, and endpoints of the remediation process. Generally speaking, this group of stakeholders is implicitly responsible for developing a remedial approach that is technically feasible and protective of human health and the environment.

With respect to sustainability, industry service providers are beginning to include a variety of sustainability metrics in their remedial alternative evaluations, remedial implementations, and remedial endpoints. Moving forward, interest is increasing for industry service providers to evaluate net sustainability impacts when considering what is protective of human health and the environment within the constraints of specific regulatory programs.

With regard to sustainability, the public's role has expanded to include participation in discussions regarding the remedy's impacts on community livability and vitality, end uses of remediated areas, and residual environmental impacts and their effects on property values and quality of life.

2.2 Significance of Remediation Activities and Available Resources

Although environmental remediation activities represent only a fraction of the U.S. economy (approximately $5 billion in 2006; Farkas & Frangdone, 2007) of the $13.8 trillion U.S. gross domestic product (U.S. Central Intelligence Agency, 2009), the remediation stakeholders who employ sustainable practices will be important role models for those who embrace the concept "think globally, act locally." In time, other industries, government agencies, and nongovernmental organizations (NGOs) may be motivated to employ sustainable practices in their own remediation endeavors.

A number of resources are currently available and are being developed to help bring sustainable decision making into the remediation field. Forward-thinking large corporations and government agencies are developing software tools to perform the necessary calculations to integrate sustainability metrics into remediation projects. Over the past two years, SURF has been discussing what works and what does not work to disseminate compatible sustainability concepts. In addition, other entities (including SURF members and nonmembers) are developing Web pages and information sheets to communicate sustainability concepts.

2.3 Current Framework for Sustainability

Although SURF members were unable to identify specific regulatory or legislative requirements for sustainable practices in environmental remediation, a number of regulatory entities and site owners are beginning to use sustainable principles during the remedy selection process. Initial green remediation activities have focused on renewable energy sources for existing remediation systems. A recent report listed 15 sites where renewable energy is being used and four sites where it is planned to be used (Dellens, 2007). The US EPA has defined "green remediation" as follows:

> The practice of considering all environmental effects of remedy implementation and incorporating options to maximize net environmental benefit of cleanup actions. (US EPA, 2008b)

Green remediation, as presented by the US EPA, is essentially the incorporation of best available engineering practices in the planning and implementation process that will maximize the net environmental benefit of a remediation project. For existing sites, these principles can be incorporated through the evaluation and optimization of the remediation approach.

SURF appears to be the first group in the United States to attempt to identify the relevant factors involved in the broad topic of sustainable practices in environmental remediation.

2.3.1 SURF Sustainable Remediation Survey

In October 2008, a nonscientific, opinion survey of SURF member organizations and environmental regulators was conducted to gauge stakeholder sentiment with regard to sustainable remediation. It should be noted that the survey was not structured so that information about the respondents' qualifications to "expertly" answer the survey questions could be assessed. The survey included questions about the perceived impediments and barriers to sustainable remediation and solicited information about sustainability regulations, policies, and guidance practiced in the United States and internationally.

The composition of responses received is shown in Exhibit 2-1. A total of 46 responses were received from SURF members. Of these responses, 27 responses (47 percent) were consultants, 11 responses (31 percent) represented industries, 4 responses (11 percent) represented academic institutions, 3 responses (8 percent) represented government agencies, and 1 response (3 percent) represented regulatory agencies. Over 160 regulators (non-SURF members) in the United States and Canada were invited to participate in the survey; 55 responses were received. Of these responses, 38 responses represented 19 state agencies, 14 responses represented U.S. federal agencies, and 1 was

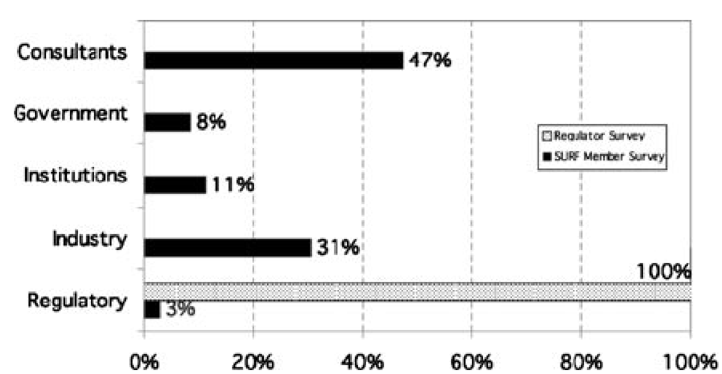

Exhibit 2-1. Composition of survey responses

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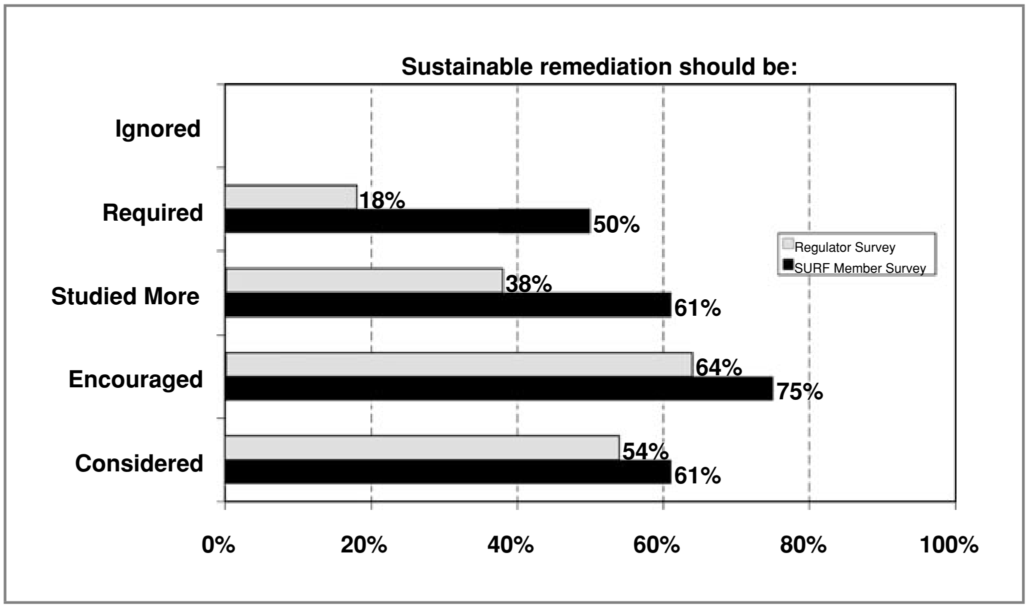

Exhibit 2-2. Future of sustainable remediation

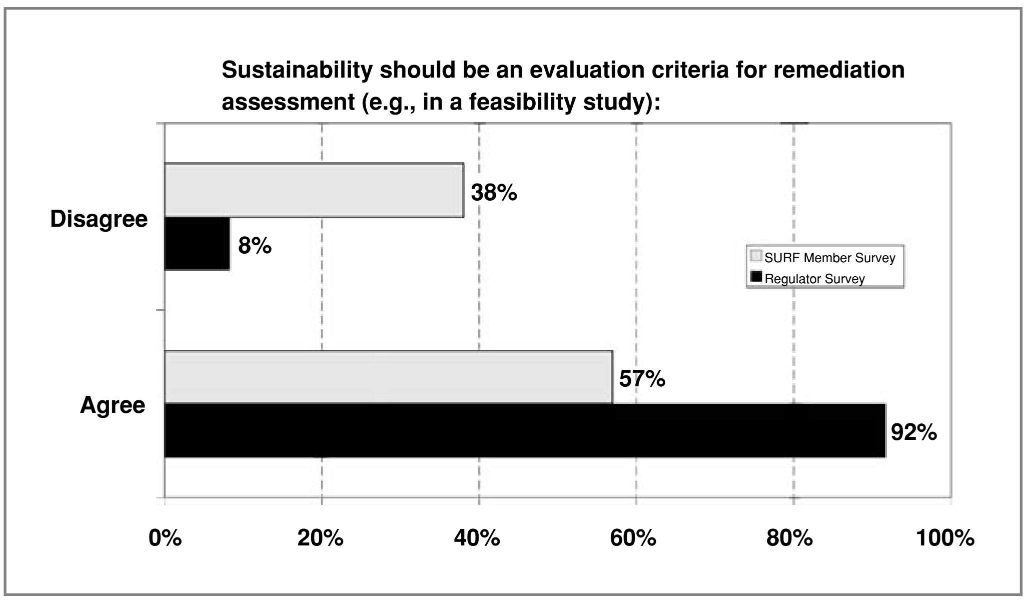

Exhibit 2-3. Evaluation criteria

from Ontario, Canada. Two of the respondents chose to remain anonymous. The survey results are illustrated in Exhibits 2-2 through 2-6 and summarized briefly in the paragraphs that follow.

Exhibit 2-2 illustrates the responses regarding the question as to whether sustainable remediation should be ignored, required, studied more, encouraged, or considered. In general, the survey responses to this question indicate that both regulators and SURF members agree that sustainable remediation is an important part of the decision-making process when selecting a remedial approach. Respondents generally indicated their support for sustainable remediation, although the degree of support was sometimes dependent on several factors. Several respondents referred to sustainable remediation as a

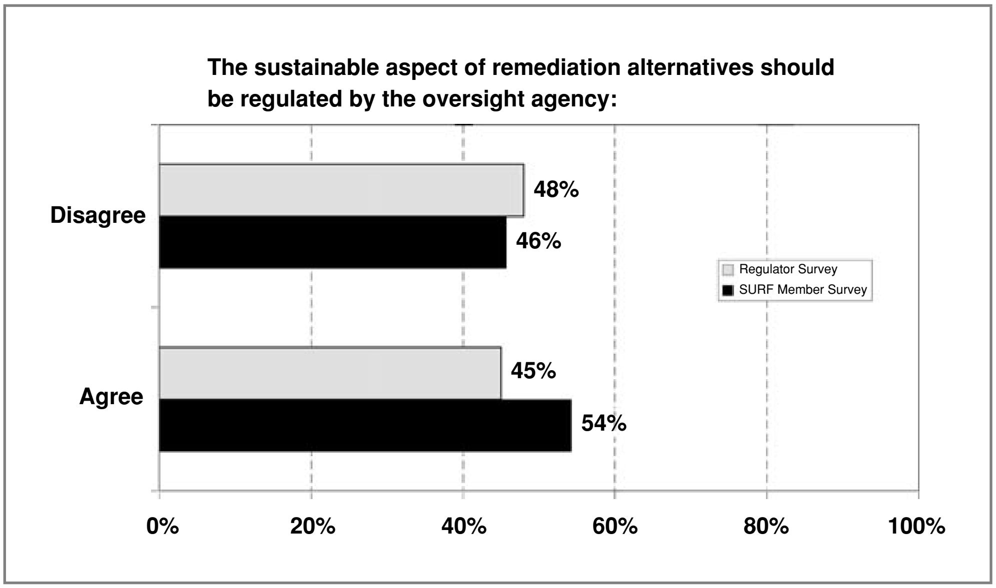

Exhibit 2-4. Regulatory oversight

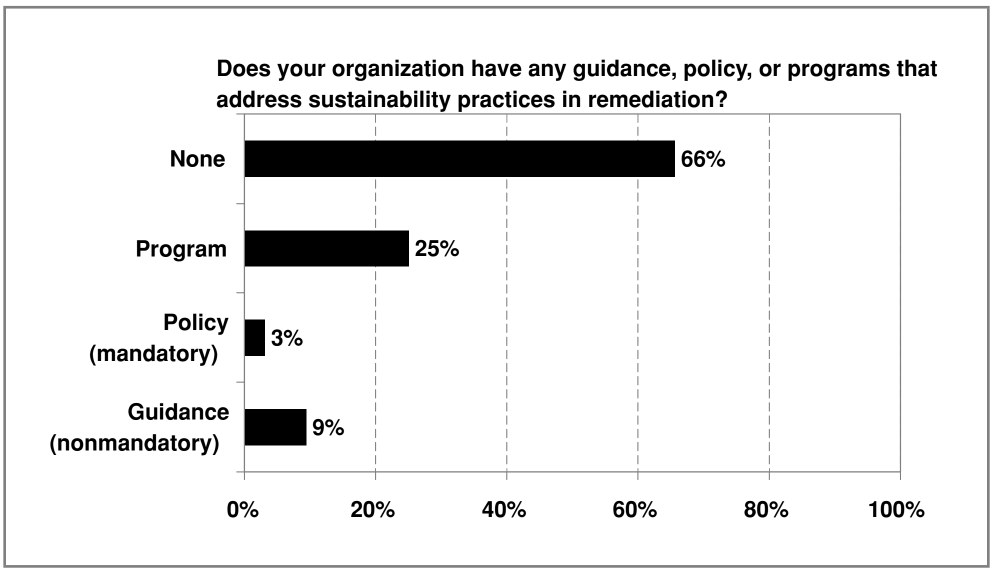

Exhibit 2-5. Organization practices

holistic approach; two respondents believe that sustainabilty is already integral to the selection of appropriate remediation technologies through an executive order.

Exhibit 2-3 illustrates the responses regarding the question of whether sustainability should be an evaluation criterion for remediation assessment (e.g., in a feasibility study). Although most survey respondents agreed that sustainability should be such a criterion, regulators represented a minority of the respondents. The responses of some regulators expressed concerns that sustainability might be used to argue against the application of more effective remediation technologies (i.e., perceived sustainability or unsustainability could override efficacy as a criterion).

When asked how sustainable remediation should be measured, the majority of SURF members responded that measurements should include life-cycle cost assessment through

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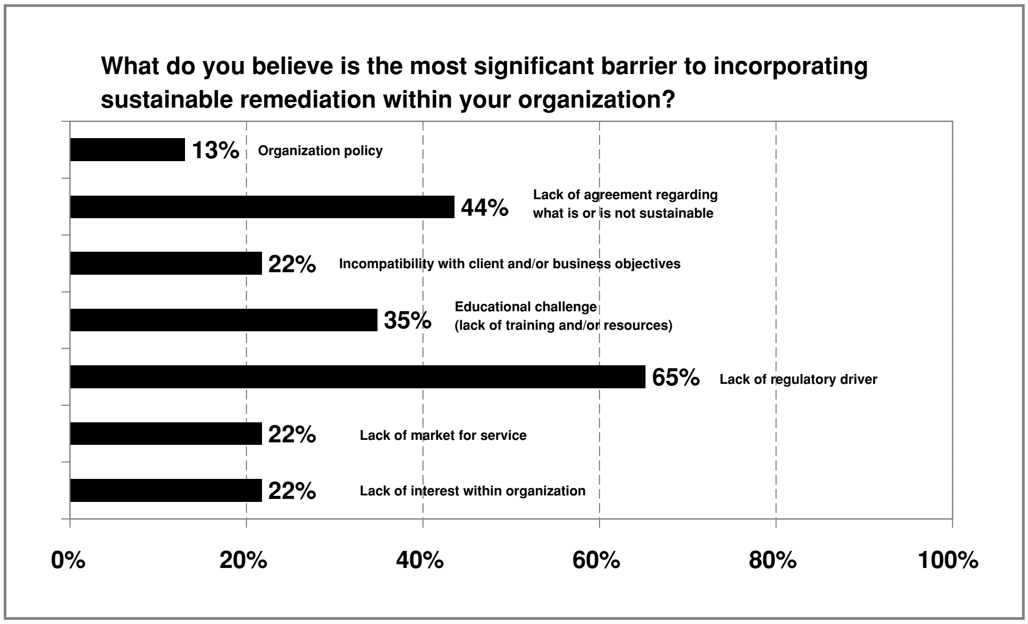

Exhibit 2-6. Barriers within organizations

various environmental, social, and economic indicators. One respondent was concerned about combining sustainability factors into the National Contingency Plan (NCP) criteria in the form of metrics. On the contrary, another respondent said that sustainability should be included as an evaluation criterion in feasibility studies.

Exhibit 2-4 illustrates the responses regarding the question of whether the sustainable aspect of remediation alternatives should be regulated by the oversight agency. Apparently, SURF members and regulators alike are evenly divided regarding the need to regulate the sustainable aspect of remediation alternatives. When asked under which mechanisms sustainable remediation should be regulated, 11 SURF members and 4 regulators said it should be by law, 8 SURF members and 10 regulators said by guidelines, and 5 regulators said that it should not be the role of the regulator.

A portion of the survey solicited respondents' general comments. Some of the challenges of including sustainability elements in remedial activities mentioned by respondents included the following:

1. Regulatory complications and/or resistance,
2. Impeding work progress,
3. Sustainability metrics override other factors,
4. Valuation of resources (e.g., how much is groundwater worth?),
5. Stakeholder education (e.g., "not in my backyard" sentiment), and
6. Incorporation of sustainability into remedy selection.

Exhibit 2-5 shows that 66 percent of SURF member respondents indicated that their organizations did not have any guidance, policy, or programs that address sustainability practices in remediation. However, 25 percent of the respondents indicated that they work with organizations that include programmatic elements of sustainability.

Unfortunately, because the survey did not include a temporal question, it is not known if the implementation of such programs is an advancing or receding area of interest.

Exhibit 2-6 illustrates respondents' beliefs about the most significant barriers to incorporating sustainable remediation within their organizations. Based on responses, significant regulatory, institutional, and perceptual challenges must be overcome to establish sustainable remediation programs, guiding principles, or policies within survey participants' organizations.

Another survey question asked if sustainable remediation is marketed as a service within SURF members' organizations; 66 percent of respondents indicated that it is not. Of those organizations that market sustainability, most listed education, training, and the use of better decision-making tools as improvements to making sustainable remediation a more integral part of their organizations.

In the United States, two federal laws are the major legal drivers for most remediation conducted under enforcement actions: CERCLA (i.e., Superfund) and the corrective action provisions of RCRA.

2.3.2 U.S. Regulatory Framework for Sustainable Remediation

As stated previously, no legislative or regulatory requirements exist to incorporate sustainable remediation principles into the remediation technology selection process. However, based on the SURF survey results, some believe it is implicit in Executive Order 13423 for federal facilities. Nevertheless, the incorporation of sustainable remediation principles in the regulatory framework is being discussed at both federal and state levels.

In order to understand how sustainable principles can be integrated into remediation projects, it is necessary to discuss the current regulatory framework. In the United States, two federal laws are the major legal drivers for most remediation conducted under enforcement actions: CERCLA (i.e., Superfund) and the corrective action provisions of RCRA. The US EPA has promulgated regulations and guidance to implement these laws, and many states have enacted similar statutes establishing similar programs.

The implementing regulations of CERCLA are set forth in the NCP (40 CFR Part 300). The CERCLA framework for evaluating alternatives considers nine criteria, as described below. The two threshold criteria that every remedy must attain are the protection of human health and the environment and compliance with applicable or relevant and appropriate requirements (ARARs). Alternatives are evaluated through a set of five balancing criteria that include short-term effectiveness; long-term effectiveness; implementability; reduction in mobility, toxicity, and volume of contaminants; and costs. State and community acceptance are the two modifying criteria that affect the selection of a preferred alternative. Detailed guidance for evaluating remediation alternatives through these nine criteria (including subset elements for each criterion) are available (40 CFR 300.430(e)(9)(iii)(A) through (I)) and have been broadly adopted in both federal and state programs for evaluating alternatives and remedy selection.

The RCRA Corrective Action Program requires owners or operators of hazardous waste treatment, storage, or disposal facilities to conduct remedial actions when there are or have been releases of hazardous wastes or hazardous constituents from solid waste management units at a facility. Unlike CERCLA, which is implemented under the NCP, the US EPA has not promulgated regulations for the RCRA Corrective Action Program. Instead, a series of guidance documents have been issued to address the remedial action process.

The RCRA Corrective Action Program is similar to the NCP process of addressing CERCLA sites, beginning with a RCRA facility investigation. This investigation is the counterpart of a CERCLA remedial investigation and is designed to characterize the

Remediation DOI: 10.1002.rem

nature and extent of contamination found at a facility. Remedial alternatives are then identified in a corrective measures study (similar to a CERCLA feasibility study) in which remedial alternatives are evaluated in a manner similar to the CERCLA process against similar criteria. Like the NCP, the RCRA program has performance standards that must be met by all remedial alternatives and uses balancing criteria to compare the alternatives. The performance standards are as follows:

1. Attainment of media cleanup standards,
2. Control of the source of the release, and
3. Protecting human health and the environment.

The balancing criteria are as follows:

1. Long-term reliability and effectiveness;
2. Reduction of toxicity, mobility, or volume of wastes;
3. Short-term effectiveness;
4. Implementability;
5. Cost;
6. Community acceptance; and
7. State acceptance.

When comparing the RCRA and CERCLA programs, it is evident that similar criteria are used for evaluating remedial alternatives. It is also evident that neither program explicitly includes sustainability among the evaluation criteria. That is not to say, however, that regulators are precluded from considering sustainability in the evaluation and selection of alternatives. Several of the evaluation criteria under both RCRA and CERCLA implicate sustainability concepts. For example, the criterion "long-term effectiveness and permanence" includes consideration of "the magnitude of residual risk remaining from untreated waste or treatment residuals remaining at the conclusion of the remedial activities" and "the uncertainties associated with land disposal for providing long-term protection from residuals" Short-term effectiveness considers impacts in the environment, community, and workers during remedy implementation (40 CFR 300.430(e)(9)(iii)(C)(*1*) and (*2*)). Sustainable remediation could easily be a necessary element for consideration under this criterion.

When comparing the RCRA and CERCLA programs, it is evident that similar criteria are used for evaluating remedial alternatives. It is also evident that neither program explicitly includes sustainability among the evaluation criteria.

In addition, sustainable principles also could be incorporated into the assessment of additional criteria such as the overall protection of human health and the environment; the reduction of toxicity, mobility, or volume through treatment; and implementability. Alternatively, a stand-alone criterion called "sustainability" (a tenth criterion) could be developed. Obviously, this addition would require discussion with regulatory agencies to consider how this tenth criterion could be factored into remedy decisions. The incorporation of the tenth criterion could be legislated, written into guidance, and/or incorporated on an ad-hoc basis.

2.4 U.S. Sustainability Activities Specific to Environmental Remediation

As previously indicated, no specific U.S. regulations or laws require the use of sustainability criteria in the design of site remediation systems. However, federal and state regulatory agencies appear to be encouraging the use of sustainability principles in the design and operation of remediation systems. Six programs or guidance for sustainability currently exist in the United States and are described below. Section 3.0 provides descriptions of some of the guidance documents and tools available.

2.4.1 US EPA's *Smart Energy Resources Guide*

The *Smart Energy Resources Guide* is a tool to help project managers assess and implement technologies and practices on sites that use modes of energy that reduce emissions (US EPA, 2008a). The guide discusses ways to reduce emissions due to energy use from remediation activities, including energy-efficiency upgrades, implementing on-site renewable energy projects, and carbon sequestration. An overview of renewable energy technologies is also presented, including costs, availability, applicability, estimated emissions reduction benefits, considerations, permitting, vendor information, funding resources, and success stories. Solar, wind, landfill gas, anaerobic digesters, and gasifiers are the renewable energy technologies included in the guide. Similar information is provided for diesel emissions reduction technologies and cleaner fuels. The guide is available at http://www.epa.gov/nrmrl/pubs/600r08049/600r08049.pdf.

To achieve green remediation goals, the US EPA Office of Solid Waste and Emergency Response (OSWER) is working with private and public partners to document the state of best management practices, identify opportunities for improvement, establish a community of practitioners, and develop mechanisms and tools facilitating the use of green practices.

2.4.2 Executive Order 13123

Executive Order 13123, *Greening the Government through Efficient Energy Management,* is one of the stimuli for the US EPA's evolving practice for green remediation. This order places greater emphasis on approaches that reduce energy consumption and greenhouse gas emissions, including:

1. Designing treatment systems with optimum efficiency and modifying them as needed,
2. Using renewable sources such as wind and solar energy to meet the power demands of energy-intensive treatment systems or auxiliary equipment,
3. Using alternate fuels such as biodiesel to operate machinery and vehicles,
4. Generating electricity from by-products such as methane gas or waste, and
5. Participating in power generation or purchasing partnerships offering electricity from large-scale renewable resources.

The document is available at http://www.ofee.gov/eo/eo13123.pdf.

To achieve green remediation goals, the US EPA Office of Solid Waste and Emergency Response (OSWER) is working with private and public partners to document the state of best management practices, identify opportunities for improvement, establish a community of practitioners, and develop mechanisms and tools facilitating the use of green practices. Partners include other federal agencies, such as the U.S. Departments of Energy, Defense, and Agriculture; state environmental agencies; and local development agencies or other organizations involved with site cleanup and revitalization. A quick reference fact sheet summarizing the OSWER green remediation program is available at http://www.epa.gov/tio/download/remed/epa-542-f-08-002.pdf. One element of this program is the Green Cleanup Standards Workgroup, which consists of OSWER program offices, US EPA regional offices, and states. The stated purpose of the workgroup is:

"To develop a voluntary standard and verification system that evaluates and recognizes efforts to maximize the net environmental benefit of cleaning up contaminated sites, an approach known as green remediation or green cleanup. The goal of the standard is to encourage and provide a documentation tool for property owners, responsible parties, developers, and communities using green cleanup practices during project planning and implementation" (Green Cleanup Initiative, January 2009, http://www.cluin.org/greenremediation/docs/Green_Cleanup_Standard_Initiative_Jan09.pdf).

2.4.3 US EPA's Green Remediation Technology Primer

Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites describes remediation methods and approaches that consider all environmental effects of cleanup actions and incorporate strategies to maximize the net environmental benefit (US EPA, 2008b). In addition, the document describes sustainable practices that more closely evaluate the core elements of a cleanup project, including energy requirements, air emissions, water requirements and associated impacts on water resources, impacts on land and ecosystems, material consumption and waste generation, and impacts on long-term site stewardship. This document is available at http://www.brownfieldstsc.org/pdfs/green-remediation-primer.pdf.

2.4.4 Minnesota's Toolkit for Greener Practices

The Minnesota Pollution Control Agency has developed a toolkit for greener practices. The toolkit is composed of an Internet-based program to promote use of pollution prevention and sustainability concepts to enhance cleanup, business operations, and site redevelopment. It describes 18 pollution prevention and sustainability options organized into the following three scenarios: cleanup remedy selection, existing and new business operations, and development and renovation. The format is a decision tree that sequentially takes the user through a series of steps in planning remediation. The toolkit also gives suggestions for streamlining the regulatory process to expedite remedial decisions. Additional information about the toolkit is available at http://www.pca.state.mn.us/programs/p2-s/toolkit/learnmore.html.

Green technologies generally include technologies that are the least disruptive to the environment, generate less waste, are recyclable, and emit fewer pollutants and greenhouse gases to the atmosphere.

2.4.5 California's Green Remediation Initiative

The California Department of Toxic Substances Control developed the Green Remediation Initiative to promote the use of green technologies in site remediation work. Green technologies generally include technologies that are the least disruptive to the environment, generate less waste, are recyclable, and emit fewer pollutants and greenhouse gases to the atmosphere. These technologies also include heavy equipment that use biodiesel fuel, energy-efficient remediation systems, and alternative energy sources to power remediation systems. The focus of the initiative is to evaluate green remediation technologies during the investigation and cleanup of active and closed military facilities, formerly used defense sites, and military munitions sites in California. Additional information about the initiative is available at http://www.dtsc.ca.gov/OMF/Grn_Remediation.cfm.

2.4.6 Illinois' Greener Cleanups Matrix

The Illinois EPA has created a matrix to guide site owners and consultants in choosing sustainable practices that can be applied to site assessment, planning and design, and cleanup. The matrix lists individual actions, followed by a qualitative ranking of their level of difficulty and feasibility (subcategorized by cost, schedule, and technical complexity). The benefits of each action to air, water, land, and energy are also identified. The matrix can be found at http://www.epa.state.il.us/land/greener-cleanups/matrix.pdf.

The Canadian Environmental Protection Act, which outlined the basic structure for environmental remediation, was implemented on March 31, 2000, by the Canadian federal government.

2.5 Canadian Sustainability Activities Specific to Environmental Remediation

The Canadian Environmental Protection Act, which outlined the basic structure for environmental remediation, was implemented on March 31, 2000, by the Canadian federal government. The tenets of the Act are as follows:

- made pollution prevention the cornerstone of national efforts to reduce toxic substances in the environment;
- set out processes to assess the risks to the environment and human health posed by substances in commerce;
- imposed timeframes for managing toxic substances;
- provided a wide range of tools to manage toxic substances, other pollution, and wastes;
- ensured that the most harmful substances are phased out or not released into the environment in any measurable quantity;
- included provisions to regulate vehicle, engine, and equipment emissions;
- strengthened enforcement of the act and its regulations;
- encouraged greater citizen input into decision making; and
- allowed for more effective cooperation and partnership with other governments and aboriginal peoples.

In follow-up action, the government published a Notice of Intent on October 21, 2006, that proposed an integrated, nationally consistent approach to the regulation of greenhouse gas and air pollutant emissions. This was followed in April 2007 with the Clean Air Regulatory Agenda. Additional information about the Clean Air Regulatory Agenda is available at http://www.ecoaction.gc.ca/news-nouvelles/pdf/20070426-1-eng.pdf.

In 1998, the Ministry of Environment of the Province of Quebec (now called the Ministry of Sustainable Development, Environment, and Parks) introduced the sustainable development concept in the guideline document entitled *Soil Protection and Contaminated Sites Rehabilitation Policy*. The following four principles formed the basis of the policy:

- Prevention Principle—The prevention principle aims to preserve the integrity of the soil in order to safeguard its ecological functions and guarantee full use of this resource now and in the future.

Remediation DOI: 10.1002.rem

- Rehabilitation-Reclamation Principle—Even if it has no impact or does not constitute a significant danger in its present state, a contaminated site remains a site at risk. Rehabilitation must not only correct the situation by decreasing the impact, but must also aim at upgrading—that is, returning a maximum number of uses to the site and reintegrating it into the cycle of sustainable development.
- Polluter-Pays Principle—The polluter is liable for the contamination s/he has caused and the impact it may have, as well as the costs of characterizing and restoring the sites s/he has damaged, and s/he may not transfer this responsibility to other members of society or to future generations.
- Fairness Principle—The action required from all owners in the same situation facing the same problems must be similar and apply equally to all at the same time.

These principles, while addressing several social and economical externalities, do not consider the environmental externalities (e.g., greenhouse gases, energy and resources usage) and the impacts on the local communities near remediation activities and are not translated into indicators or metrics. The 1998 policy also includes a framework for risk-based corrective actions, but excludes petroleum hydrocarbons from this approach. Consequently, most of the remediation work in Quebec is conducted primarily to comply with generic criteria.

The application of these principles as described above has resulted in a situation where 67 percent of the soil remediation work completed in Quebec to date falls into the category of "excavation and off-site landfill," while another 29 percent fits into "excavation and *ex situ* treatment."

The European Union adopted the Environmental Technology Action Plan in 2004 to encourage the development and broader use of environmental technologies. This plan applies to industrial processes and environmental remediation technologies.

2.6 European Sustainability Activities Specific to Environmental Remediation

The European Union adopted the Environmental Technology Action Plan in 2004 to encourage the development and broader use of environmental technologies. This plan applies to industrial processes and environmental remediation technologies. Another initiative known as the European Coordination Action for Demonstration of Efficient Soil and Groundwater Remediation was started in 2004 as the central platform for technology demonstration of soil and groundwater management in the field. Also known as EURODEMO, its overall objective is to coordinate European soil and groundwater management technology demonstrations in terms of cooperation, exchange of experiences, and development of common protocols.

EURODEMO's efforts are seen as an important vehicle in achieving the priority goals of the European Sustainable Development Strategy, which sets overall objectives and concrete actions for seven key priority challenges until 2010. According to the European Commission's Web site (http://ec.europa.eu/environment/eussd), the overall aim of the strategy is "to identify and develop actions to enable the European Union to achieve a continuous, long-term improvement of the quality of life through the creation of sustainable communities." The goal is for communities to be able to manage and use resources efficiently; tap ecological and social innovation potential within the economy; and ensure prosperity, environmental protection, and cohesion.

European sustainability activities specific to environmental remediation are described briefly below.

2.6.1 Contaminated Land: Applications in Real Environments

Contaminated Land: Applications in Real Environments (CL:AIRE) describes itself as an independent, not-for-profit organization established to stimulate the regeneration of contaminated land in the United Kingdom by raising awareness of and confidence in practical sustainable remediation technologies. CL:AIRE is currently leading the Sustainable Remediation Forum—United Kingdom (SURF UK). The working mission statement of the group is "to develop a framework in order to embed balanced decision making in the selection of the remediation strategy to address land contamination as an integral part of sustainable development." Additional information about the organization is available at http://www.claire.co.uk/.

Contaminated Land: Applications in Real Environments (CL:AIRE) describes itself as an independent, not-for-profit organization established to stimulate the regeneration of contaminated land in the United Kingdom by raising awareness of and confidence in practical sustainable remediation technologies.

2.6.2 Network for Industrially Contaminated Land in Europe

The Network for Industrially Contaminated Land in Europe (NICOLE) is a leading forum on contaminated land management in Europe, promoting cooperation between industry, academia, and service providers on the development and application of sustainable technologies. The objectives of the organization are to disseminate and exchange knowledge and ideas about contaminated land, identify research needs and promote collaborative research to assess and manage contaminated sites more efficiently and cost-effectively, and collaborate with other international networks. Additional information about the organization is available at http://www.nicole.org/.

2.6.3 Soil and Groundwater Technology Association

The Soil and Groundwater Technology Association (SAGTA) is a nonprofit association of member organizations drawn from UK companies representing many major industry sectors. Its members actively address the technical challenges associated with contaminated land management. A key component of the association's activities is regular dialogue with policymakers, regulatory agencies, and local authorities to facilitate a common understanding of the issues. As well as addressing contamination from past activities, SAGTA members also use best practice methods to prevent future contamination. In addition, the association responds to many aspects of proposed technical policy in the United Kingdom. Additional information about the organization is available at www.sagta.org.uk.

NICOLE and SAGTA sponsored a Sustainable Remediation Workshop in March 2008. The presentations were divided into two themes: defining sustainable remediation and discussing how sustainable development might be better implemented in remediation. Several speakers from NICOLE, SAGTA, and English Partnerships provided viewpoints. Participants presented papers from the United Kingdom, Austria, and Switzerland that explored industry and regulatory issues in more detail. A series of case studies of decision support approaches and examples of sustainable remediation were also presented. Additional information about the workshop is available at http://www.eugris.info/Displayresource.asp?resourceID=6447.

Remediation DOI: 10.1002.rem

2.7 Australian Sustainability Activities Specific to Environmental Remediation

The first of four of Australia's national research priorities presented by the prime minister in 2002 reveals a commitment to areas of research in environmental technology and management for the future of Australia's environment. The first priority is "An Environmentally Sustainable Australia," which focuses on new, cost-effective, and safe ways to detect, assess, and remediate contaminated urban, rural, or industrial sites, thus enabling the sustainable use of land. Additional information on this priority as well as the other priorities is available at http://www.dest.gov.au/sectors/research_sector/policies_issues_reviews/key_issues/national_research_priorities/default.htm.

2.8 South American Sustainability Activities Specific to Environmental Remediation

The State of São Paulo (Brazil) is often considered in South America as a reference in terms of environmental regulations. Since 1999, São Paulo has implemented a remediation approach promoting risk-based corrective actions. The São Paulo agency CETESB accepts risk-based corrective action (RBCA) methodology based on US EPA protocols for conducting risk assessments at service stations. However, the agency has experienced a wide variability in the risk assessments received, which has led to development of a standard spreadsheet that is used to calculate risk at service stations. This spreadsheet will most likely be used at industrial sites as well and is expected to be released to the public no later than March 2009.

Although there is currently no official framework or protocol in Brazil applicable to evaluating and measuring sustainable practices and impacts in remediation, conditions are favorable for the promotion and implementation of sustainable activities. An example of this is the presence of Petrobras, the largest oil company in South America and the largest corporation in Brazil. All of Petrobras's activities, including the remediation of contaminated sites, are governed by a set of ten social and environmental principles. Petrobras is a United Nations Global Compact signatory and is listed on the Dow Jones sustainability index. The company is recognized as one of the most sustainable and influential Brazilian companies.

The first of four of Australia's national research priorities presented by the prime minister in 2002 reveals a commitment to areas of research in environmental technology and management for the future of Australia's environment.

2.9 Asian Sustainability Activities Specific to Environmental Remediation

2.9.1 China

Economic growth in Asia/China has been impressive over the past 15 years, with strongly positive impacts on reducing poverty. However, the increased pollution resulting from such economic growth has degraded natural resource systems, is threatening public health, and is undermining economic productivity. Although the situation varies by Asian countries, the demands on improving environmental quality have increased. The environmental needs are to clean up polluted rivers, control urban air pollution, address solid waste management, locate and mitigate the impacts of previously disposed toxic and hazardous wastes, and restore damaged ecosystems.

 Remediation DOI: 10.1002.rem

Efforts have been focused on accelerating contaminated land cleanup and putting development on a more sustainable path by encouraging the use of clean and renewable energy resources and by providing efficient public transport systems. Specific sustainable approaches and/or the development of cleanup strategies for contaminated lands were lacking at the time of this publication; however, policy guidelines for renewable energy resources are available in some Asian countries. For example, a policy guideline on sustainable energy was released by China's government on June 5, 2008. Rather than a call to action, the policy guideline is primarily the government's show of agreement regarding sustainability concepts. Additionally, in Taiwan, the soil and groundwater pollution remediation act that was promulgated in 2000 and associated efforts remain in preliminary stages. It appears that sustainability principles will not play a significant role in remediation technology selection in China and Taiwan until a significant number of sites move into the remediation phase.

It appears that sustainability principles will not play a significant role in remediation technology selection in China and Taiwan until a significant number of sites move into the remediation phase.

2.9.2 Japan

Although most remediation activities in Japan are influenced by the Soil Contamination Countermeasures Law of 2003, it is SURF's understanding that Japan's Environment Agency has initiated discussions regarding the applicability of sustainability in remediation. According to the Secretary General of the Geo-Environmental Protection Center, Japanese law is currently being reviewed, with potential revisions available for public comment in early 2009. However, the Secretary General anticipates that the law will be revised without addressing the issues pertaining to sustainability in remediation.

2.10 General Sustainability Activities

This section describes the status of other general sustainability activities that could be linked to environmental remediation. Concepts of sustainability, broadly defined here as judicious, long-term management of resources, have been applied to a wide range of activities, including (but not limited to) remediation. Because many aspects of these more general sustainability systems contain elements that include or can be extended to remediation, this section summarizes the more general sustainability programs by country.

One example of efforts by a group to encourage global cooperation on sustainability issues is the World Business Council for Sustainable Development (www.wbcsd.org). This is an organization that has approximately 200 members drawn from more than 35 countries and 20 major industrial sectors, involving some 1,000 business leaders globally. The World Business Council for Sustainable Development is concentrating its efforts on four major focus areas: energy and climate, development, the business role, and ecosystems.

2.10.1 United States

The incorporation of sustainable activities into the U.S. government has been introduced primarily through a series of executive orders from the President. These executive orders are described in Exhibit 2-7. The environmental management activities that have been initiated in response to the executive orders are briefly described in the paragraphs that follow.

 Remediation DOI: 10.1002.rem

Exhibit 2-7. Executive orders (EOs)

1. EO 13101: *Greening the Government through Recycling and Waste Reduction*—Requires federal agencies to use copy paper with at least 30 percent postconsumer recycled content.
2. EO 13123: *Greening the Government through Efficient Energy Management*—Sets goals for reductions in greenhouse gases and energy use, increased use of renewable energy (and decrease use of petroleum-based fuels), and conservation of water. The EO also requires federal agencies to apply sustainable design principles to the siting, design, and construction of new facilities.
3. EO 13134: *Developing and Promoting Biobased Products and Bioenergy*—Sets goals for use of biobased products and bioenergy.
4. EO 13148: *Greening the Government through Leadership in Environmental Management*—Sets specific goals for compliance with environmental laws, pollution prevention, reduction of releases and off-site transfers of toxic chemicals; phaseout of ozone-depleting substances; and implementation of environmentally sound landscaping practices to reduce adverse impacts to the environment.
5. EO 13149: *Greening the Government through Federal Fleet and Transportation Efficiency*—Establishes goals for the reduction of petroleum consumption.
6. EO 13423: *Strengthening Federal Environmental, Energy, and Transportation Management*—Consolidates EOs 13101, 13123, 13134, 13148, and 13149 and updates goals, practices, and reporting requirements for vehicles, petroleum use, use of alternative fuels and renewable power, reduction of greenhouse gases, water conservation, procurement of biobased products, purchase and disposal of electronics products, and implementation of environmental management systems. A companion document to the EO developed by the Interagency Sustainability Working Group is EO 13423 (*Technical Guidance for Implementing the Five Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings*). This guidance provides instructions on how to implement the EO in specific areas; specific examples include storm water runoff mitigation, energy efficiency, and construction waste. An example of a specific instruction with respect to construction waste is recycling or salvage of at least 50 percent construction, demolition, and land clearing waste.

Agency- and subagency-specific implementation policies for environmental management systems (EMSs) have been adopted by the U.S. Departments of Defense, Energy, Interior, Commerce, and Agriculture; the US EPA; and the U.S. Air Force, Army, Navy, Marine Corps, Coast Guard, and Corps of Engineers. The goal set for EMS implementation at federal facilities for 2010 is at least 2,500, up from approximately 1,000 in 2007. From 1985 to 2005, the federal government reduced petroleum consumption by 70 percent in buildings, improved energy efficiency by approximately 30 percent, built energy use by about 13 percent, reduced greenhouse gas emissions by 22 percent (1990 to 2005), and reduced water consumption by 20 percent (2000 to 2005; Office of the Federal Environmental Executive, 2007).

In addition to the general sustainability activities listed above, the U.S. Army and Air Force have remedial systems evaluation and optimization programs in place. Although not specific to sustainability, they consider several aspects (e.g., energy use) that are often sustainability evaluation criteria. In addition, the US EPA has published a series of instruction, guidance, and policy documents to incorporate sustainability into remedial technology evaluations. A listing of these documents is provided in Exhibit 2-8.

Many general sustainability programs also exist on the state and local level in the United States. A good resource for finding the specific programs in each state (and each

Exhibit 2-8. US EPA instruction, guidance, and policy documents for the incorporation of sustainability

1. Green Chemistry (http://www.epa.gov/opptintr/greenchemistry/)—Program promotes innovative chemical technologies that reduce or eliminate the use or generation of hazardous substances in the design, manufacture, and use of chemical products.
2. Green Engineering (http://www.epa.gov/opptintr/greenengineering/)—Program promotes the design, commercialization, and use of processes and products that are feasible and economical while minimizing the generation of pollution at the source and any risks to human health and the environment.
3. Product Stewardship (http://www.epa.gov/epr/index.htm)—Web site that includes products that support sustainable development and highlights the latest developments in product stewardship, both in the United States and abroad.
4. Environmentally Preferred Purchasing (http://www.epa.gov/oppt/epp/about/about.htm)—Federal-wide program that encourages and assists executive agencies in the purchasing of environmentally preferable products and services.
5. Green Communities Assistance Kit (http://www.epa.gov/greenkit/)—Guide for identifying and resolving community needs and planning and implementing sustainable actions.
6. ENERGY STAR (http://www.energystar.gov/)—A government-backed program helping businesses and individuals accomplish energy efficiency.
7. The Design for the Environment (http://www.epa.gov/opptintr/dfe/)—Partnership that supports projects that promote the integration of sustainable methods into business practices.
8. Green Buildings (http://www.epa.gov/opptintr/greenbuilding/)—Practice of creating and using more resource-efficient models of construction, renovation, operation, maintenance, and demolition.
9. Smart Reuse: A Guide to Sustainable Redevelopment of Brownfield Properties (http://www.epa.gov/reg3hwmd/bfs/smart_reuse/)—Web site that contains information to minimize the environmental impact of brownfield redevelopment projects.
10. Brownfields Cleanup and Redevelopment Homepage (http://www.epa.gov/swerosps/bf/index.html)—Web site that provides links to information on industrial and commercial facilities where expansion or redevelopment is complicated by environmental contamination.
11. Sustainable Urban Environment (http://www.epa.gov/Region5/sue/index.htm)—Web site that describes efforts to lessen environmental degradation impacts of development or redevelopment.
12. Community-Based Environmental Protection (http://www.epa.gov/ecocommunity/)—Program that integrates environmental management with human needs and considers long-term ecosystem health.
13. Sustainable Landscaping (http://www.epa.gov/greenacres/)—Web site that describes landscaping practices that use native plants that do not need fertilizers, herbicides, pesticides, or watering.
14. Environmentally Preferred Purchasing (http://www.epa.gov/oppt/epp/)—Web site that provides guidance, case studies, tools, and other resources to procure environmentally preferable products and services.
15. Green Meetings (http://www.epa.gov/oppt/greenmeetings/index.htm)—Web site that provides information on planning meetings that minimize negative impacts on the environment.
16. Environmental Labeling (http://www.epa.gov/opptintr/epp/documents/labeling.htm)—Web site that provides guidance for label information methods that inform consumers about product characteristics that may not be readily apparent.
17. Environmental Accounting (http://www.epa.gov/opptintr/acctg/)—Program where the US EPA has partnered with the Tellus Institute to maintain and further develop tools and documentation on environmental accounting.

Remediation DOI: 10.1002.rem

Exhibit 2-9. Multistate Governmental Programs

- Alternative Fuels and Advanced Vehicles Data Center
  The Alternative Fuels and Advanced Vehicles Data Center was developed in 1991 in response to the Alternative Motor Fuels Act of 1988 and the Clean Air Act Amendments of 1990. The Web site (http://www.afdc.energy.gov/afdc/) features a database with state and federal laws and incentives related to alternative fuels and vehicles, air quality, fuel efficiency, and other transportation-related topics.
- Database of State Incentives for Renewal Energy
  Established in 1995, the Database of State Incentives for Renewable Energy (DSIRE) is an ongoing project of the Interstate Renewable Energy Council (IREC), funded by the U.S. Department of Energy and managed by the North Carolina Solar Center. The organization's mission is to accelerate the use of renewable energy sources and technologies in and through state and local government and community activities.

Other organizations with statewide or local sustainability activities include the following:

- Renewable Portfolio Standards, American Wind Energy Association (http://www.awea.org/policy/rpsbrief.html)—standards that can be adopted by individual states to assure a specified percentage of electricity demand is supplied from renewable energy sources.
- U.S. Mayors' Climate Protection Agreement (http://www.seattle.gov/mayor/climate/)—agreement that calls for the achievement of the standards set in the Kyoto Treaty (by November 1, 2007, there were more than 410 signatories to the Agreement).
- International Council for Local Environmental Initiatives (ICLEI) (http://www.iclei.org/)—an international association of local governments and national and regional local government organizations that have made a commitment to sustainable development.
- The Climate Registry (http://www.theclimateregistry.org/)—A nonprofit partnership developing a greenhouse gas emissions measurement protocol that is capable of supporting voluntary and mandatory greenhouse gas emission reporting policies for its members and reporters. Forty-one states and the District of Columbia in the United States are currently members.

locality within each state) is the Center for Sustainability at Aquinas College (http://www.centerforsustainability.org/resources.php?root=91&category=94). A listing of some of the state and local programs is provided in Exhibit 2-9.

A number of nongovernmental organizations (NGOs) are also focusing on sustainability issues in the United States. The Chicago Climate Exchange and the U.S. Business Council for Sustainable Development (USBCSD) are two examples and are discussed below.

The Chicago Climate Exchange, started in 2003, describes itself as the world's first and North America's only active voluntary legally binding integrated trading system to reduce emissions of all six major greenhouse gases. The exchange provides independent third-party verification by the Financial Industry Regulatory Authority (FINRA). Emitting members make a voluntary, but legally binding, commitment to meet annual greenhouse gas emission reduction targets. The exchange trades Carbon Financial Instrument (CFI) contracts, which represent 100 metric tons of carbon dioxide equivalents. Recent pricing (December 31, 2008) was U.S. $1.65 per CFI. Based on a personal communication with a Chicago Climate Exchange representative, remediation project carbon dioxide equivalents are not included in the members' annual commitments. Additional information is available at www.chicagoclimatex.com.

The U.S. Business Council for Sustainable Development (www.usbcsd.org) is a group of leading corporations seeking collaborative, nonconfrontational approaches to environmental protection, stewardship, and community development. Members gain opportunities to work constructively with local, state, and federal governments; NGOs; and industries to define the values of sustainable development. Under the Ecosystem Services Platform, the USBCSD has defined an objective, which is "to develop process models and pilot projects to demonstrate how responsible parties can conserve and restore natural resources cost-effectively through innovative market mechanisms that address real barriers and engage important stakeholders." The first project the group is involved with is known as the Houston/Galveston Green Brownfields Initiative.

Under the Ecosystem Services Platform, the USBCSD has defined an objective, which is "to develop process models and pilot projects to demonstrate how responsible parties can conserve and restore natural resources cost-effectively through innovative market mechanisms that address real barriers and engage important stakeholders."

The U.S. Business Council for Sustainable Development is a regional affiliate of the World Business Council for Sustainable Development.

2.10.2 Canada

On October 21, 2006, the Canadian government published a Notice of Intent, which proposed an approach to the regulation of greenhouse gas and air pollutant emissions in order to protect human health and the environment. This was followed in April 2007 with the Clean Air Regulatory Agenda, which outlined a voluntary program for carbon offsets under the supervision of Environment Canada (2007). Additional information about the agenda is available at http://www.ecoaction.gc.ca/news-nouvelles/pdf/20070426-1-eng.pdf. These regulations are part of the larger strategy of Canada with respect to regulating greenhouse emissions. This strategy is outlined in two documents developed by Environment Canada (2008a, 2008b) and provided at http://www.ec.gc.ca/doc/virage-corner/2008-03/541_eng.htm and http://www.ec.gc.ca/doc/virage-corner/2008-03/526_eng.htm. The Canadian province of British Columbia began implementing a tax on carbon-based fuels of $10 per ton of greenhouse gases generated in August 2008.

2.10.3 Mexico

The Mexico Green Building Council, an NGO of parties in the construction industry, has joined efforts to promote sustainable building technology, policy, and best practice. Additional information is available at http://www.mexicogbc.org/mexicogbc/acerca_e.htm.

2.10.4 Europe

The European Climate Exchange was started by the Chicago Climate Exchange in 2005. The exchange claims to be the leading exchange in the European Union Emissions Trading Scheme, handling over 80 percent of the exchange-traded volume. Contracts representing 1,000 metric tons of carbon dioxide European Union Allowances (EUAs) and Certified Emissions Reductions (CERs) are traded on the exchange. Recent prices (December 31, 2008) for EUAs were approximately €27 and €19 per CER. It is unclear if remediation project carbon dioxide equivalents are included in these contracts. Additional information is available at www.europeanclimateexchange.com.

 Remediation DOI: 10.1002.rem

2.10.5 Australia

The organizations promoting general sustainability programs in Australia are listed below, and associated activities are described briefly in the paragraphs that follow.

- the Australia Government Department of the Environment, Water, Heritage, and the Arts;
- the Advancing Green Infrastructure Council (AGIC);
- the Cooperative Research Center for Contamination Assessment and Remediation of the Environment (CRCCARE); and
- the Australian Department of Climate Change.

The Australia Government Department of the Environment, Water, Heritage, and the Arts has developed a series of programs aimed to incorporate sustainable practices in industry and includes the EMS. The Environmental Policy of the EMS is a statement of what an organization intends to achieve from an EMS. It ensures that all environmental activities are consistent with the organization's objectives.

The AGIC is a not-for-profit industry association and governed by a board of directors. Formed initially by a collection of professionals operating in the infrastructure sector in mid-2007, the AGIC is currently led by an Interim Steering Group comprised of unpaid directors and supported by three working groups (all of which are composed of volunteers from across Australia) and a paid administration support contractor. The vision of the AGIC is to be a catalyst for delivering more sustainable outcomes from Australian infrastructure through the development, delivery, and operation of a sustainability rating scheme and the provision of tools, leadership, training, and direction to assist industry in achieving sustainable infrastructure outcomes. The rating scheme will assess the incorporation of environmental, social, and economic aspects against benchmarks in sustainable infrastructure design, construction, and operation. It is proposed that the scheme will cover the infrastructure types that include remediation sites. Additional information is available at http://www.agic.net.au/Documents/AGIC_IBC_Exec_Summary.pdf.

The Australia Government Department of the Environment, Water, Heritage, and the Arts has developed a series of programs aimed to incorporate sustainable practices in industry and includes the EMS.

The CRCCARE is a partnership of organizations set up to develop new ways of addressing and preventing soil, water, and air contamination. Established and supported under the Australian government's Cooperative Research Centers Program, the group's research activities include risk assessment; remediation technologies; prevention technologies; social, legal, policy, and economic issues; and the National Contaminated Sites Demonstration Program (NCSDP). CRCCARE has initiated activities to comply with the first of four National Australian research priorities, as discussed in Section 2.7.

The Australian Department of Climate Exchange published the *Carbon Pollution Reduction Scheme Green Paper* in July 2008 to solicit feedback from the business and household community regarding the proposed regulatory limits or caps, requirements, costs, and controls on carbon pollution. The scheme primarily pertains to polluters that produce greater than 25,000 tons of carbon pollution each year, representing less than 1 percent of Australian businesses. If the scheme is adopted, it would require business and industry to buy a pollution permit for each ton of carbon they contribute to the atmosphere, giving a strong incentive to reduce greenhouse gas emissions as defined in the Kyoto Protocol. The Carbon Pollution Reduction Scheme is built on the work of previous

Australian government task groups and from lessons learned from the European Climate Exchange program. Additional information is available at http://www.climatechange.gov.au/greenpaper/index.html.

2.11 Summary of Current Status

Sustainable remediation is a developing area of interest among stakeholders, including site owners, regulatory entities, the public, and industry service providers that are financially and vocationally accountable for the cleanup of contaminated sites. Sustainable remediation is broadly described as a remedy or combination of remedies whose net benefit on human health and the environment is maximized through the judicious use of limited resources. While the process or programmatic components of sustainable remediation are the subject of considerable debate, stakeholders agree that resource use should be evaluated and that sustainable remediation plans should include a disciplined evaluation of the potential net environmental benefit of the application (or lack of application) of various remediation alternatives. Section 6.0 presents representative examples of assessments where sustainability was an explicit element in the overall assessment performed by many organizations.

Richard L. Raymond Jr., is the president of Terra Systems Inc., which is a bioremediation products and services company. During the past 23 years, he has designed and managed numerous successful *in situ* and *ex situ* soil and groundwater bioremediation projects in the United States, South America, Japan, and Europe. He received his BA/BS degree from American University in Washington, DC, and an MBA from Temple University in Philadelphia, Pennsylvania.

Carol Lee Dona, PhD, P.E., is a chemical engineer at the U.S. Army Corps of Engineers Environmental and Munitions Center of Expertise in Omaha, Nebraska. Her areas of interest are incorporation of sustainable practices into environmental remediation and evaluation and implementation of *in situ* and *ex situ* remedies. She is currently working on developing a decision framework for incorporation of sustainability throughout the environmental remediation process for Army projects. Dr. Dona received her BS in chemistry from University of Washington, her MS in mechanical engineering from the University of Missouri, and her PhD in chemical and petroleum engineering from the University of Kansas.

Elie H. Haddad, P.E., is a vice president of Haley & Aldrich Inc in San Jose, California. With over 20 years of experience, his focus is in the area of site strategies, as well as vapor intrusion, soil, and groundwater investigation and remediation. He received his BS and MS in civil engineering from the Georgia Institute of Technology.

Lowell G. Kessel, P.G., is the founder of EnviroLogek, LLC, in Los Angeles, California. EnviroLogek is an international environmental products distribution firm focusing on remediation technologies and monitoring equipment for the environmental engineering community. He received his BS and MS in geological sciences and an MBA from the University of California.

 Remediation DOI: 10.1002.rem

Phillip D. McKalips, P.G., is a principal, vice president, and geoscientist with Environmental Standards Inc. He is also the regional office manager for the firm's Central Virginia office. He has over 20 years of experience practicing on a wide variety of environmental and geotechnical projects, primarily focused on groundwater and remediation. He received his BS in geosciences from The Pennsylvania State University.

Charles Newell, PhD, P.E., is vice president of GSI Environmental Inc. He is a member of the American Academy of Environmental Engineers, a National Ground Water Association (NGWA)–certified groundwater professional, and an adjunct professor at Rice University. He has coauthored three US EPA publications, five environmental decision support software systems, numerous technical articles, and two books, *Natural Attenuation of Fuels and Chlorinated Solvents* and *Ground Water Contamination: Transport and Remediation*.

Raymond J. Vaské is a project engineer with URS Corporation in Cincinnati, Ohio. His focus is on the remediation of chlorinated hydrocarbon impacts to groundwater and soil. His current studies include bioremediation using vegetable after-market and processing wastes. He received his BS in civil engineering with an environmental focus from the University of Cincinnati.

3.0 SUSTAINABILITY CONCEPTS AND PRACTICES IN REMEDIATION

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Tiffany N. Swann

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David S. Woodward

Conventionally, the selection of a remediation technology is based on factors such as the effectiveness of the remedy, implementability, cost considerations (capital and operating), and time constraints. Protection of the public via interception of contaminants, reduction of source(s), and mitigation of exposure pathways are prerequisites of remedy selection. Although these considerations are critical components in a traditional evaluation of remediation options, they do not evaluate and balance fully the external environmental, social, and economic impacts of a project. Said differently, the conventional approach generally focuses on the "internalities" of a project and gives very little attention to its "externalities."

Internalities—*remedial objectives, system performance, environmental impacts local to the remediation site such as waste generation, water discharge, and air emissions (generally required by permit)*

Externalities—*environmental impacts at the community, regional, and global levels*

A variety of approaches and tools that are currently available and applicable to assessing sustainable practices in remediation are outlined in this section. Some of the tools presented here are primarily qualitative, but a scoring component is included that allows comparison of remediation technologies. The qualitative approach is perhaps best employed at the outset of a project, when screening multiple remediation options. The remaining tools outlined herein are quantitative; some of the metrics are carbon dioxide emissions, energy consumption, and occupational risk.

Metric—*measure for something; in this case, the indicators by which performance is determined*

Some of the newer tools normalize remediation performance (e.g., the mass of contaminant removed or the volume of water remediated) to currency or environmental impacts such as carbon dioxide equivalents and water usage. These normalizations can also be considered as efficiency measurements. As carbon dioxide becomes a more commonly traded commodity, as discussed in the previous section, it seems likely that most tools for studying the environmental impacts of remediation will have a numeric component. Most of the existing quantitative tools are holistic and take into account multiple environmental impacts, as well as societal and economic effects. The quantitative tools presented have primarily been used predictively to help evaluate remediation technologies. It may also be useful to apply these tools retrospectively and examine the impacts of existing remediation projects with an eye toward how the current implementation of remediation technologies might be changed. Some of this analysis will be conducted at service station sites in the United States, but the work is just beginning (Fiorenza et al., 2009).

The field of sustainable remediation is growing and changing rapidly. SURF has attempted to survey and present the most widely available approaches and tools in this section. Tools that were in development at the time of this writing or only privately available may have been omitted. Also lacking is information on whether any directly measurable environmental benefit was derived for the environmental costs associated with certain types of conventional remedies.

Remediation DOI: 10.1002.rem

Approach—*a methodology used to assess sustainability of a remediation* **Tools—***all* **Tools** *are* **Approaches***, but the subset of* **Tool** *implies a ranking or quantitative result*

Site assessment and performance monitoring are also discussed in this section because the measurement of sustainability parameters may require the collection of unconventional data throughout the remediation process. Ultimately, tools for measuring sustainable remediation can and will be applied from the beginning of a remediation project in the site assessment phase to remedy selection and, ultimately, during system operation. Efficiency measures, such as normalizing the environmental impact with the unit of remediation (as discussed in Section 3.2.5), will help to verify performance and aid in meeting site cleanup and closure goals.

3.1 Site Assessment and Sustainability

Conventional site-assessment methods offer many opportunities for incorporating sustainable practices, but few of these tools have been developed with the explicit purpose of allowing sustainability to be characterized or otherwise measured. Despite this, many of the advanced site-characterization tools employ the principles of sustainability in their design or offer data that can be used to characterize the sustainability of remedial options. This section discusses which sustainable practices potentially apply to site assessment.

In 2008, the US EPA incorporated the concept of sustainable remediation in a technical primer document (US EPA, 2008b). The document discusses the incorporation of best management practices, including sustainable practices. Sustainable practices for site assessment presented in the US EPA document are: (1) waste minimization (e.g., use of low-flow sampling techniques and passive groundwater samplers), (2) the management and tracking of investigation-derived waste from site-assessment work, (3) the incorporation of practices that rely on recycling and reusing materials to the greatest extent possible, (4) the use of low environmental impact equipment and alternative energy sources, and (5) the use of geophysical tools to minimize investigation-derived waste generation and soil disturbance with mechanical drilling rigs.

The Triad approach (Interstate Technology and Regulatory Council [ITRC], 2003) incorporates similar sustainable practices as part of its work strategies. Exhibit 3-1 provides examples of available sustainable practices as they relate to currently employed site-assessment technologies.

The Triad Approach *1) Systematic Planning* *2) Dynamic Work Strategies* *3) Real-Time Measurement Technologies*

3.2 Assessing Sustainable Practices in Remediation

This section provides a review of the approaches and tools that are currently being used or that have been used across the globe to estimate the impacts of remediation systems on sustainability parameters. Where an approach is more developed, an application of the

Exhibit 3-1. Examples of sustainable practices for site assessment that incorporate innovative technologies

Technology	Sustainable Practices	Applications	Advantages	Limitations	Technical References
Direct-push tools for monitoring-well installation	Installation of monitoring wells using direct-push tools (e.g., GeoProbe®).	For use in unconsolidated materials to average depths up to 100 feet. Direct-push wells can be installed with a single-screened interval or specialized multilevel monitoring systems.	1) Requires less materials, energy, and time for installation than conventional monitoring wells. Therefore, direct-push rigs minimize investigative-derived waste (IDW) and energy consumption. 2) Minimizes rig mobilization/demobilization energy requirements and air emissions, as direct-push rigs are generally smaller than conventional hollow-stem auger rigs.	1) Many U.S. state regulations do not permit direct-push monitoring wells for long-term site monitoring because two-inch annular spaces cannot easily be achieved.	Einarson, 2006 Nielsen et al., 2006 US EPA, 1993 US EPA, 1997 US EPA, 2005
Direct-push tools for groundwater and soil sampling	Use of direct-push tools to collect depth-discrete soil and groundwater samples as a substitute for installation of conventional monitoring wells when only one sampling event is needed (e.g., piston and dual-tube samplers for soil sampling and protected screen samplers and vertical profilers for groundwater sampling).	For use in unconsolidated materials to depths of up to 50 to 100 feet, depending on site lithology.	1) Requires less materials, energy, and time for collection than conventional monitoring-well installation and sample collection. Therefore, direct-push rigs minimize IDW and energy consumption. 2) Minimizes rig mobilization/demobilization energy requirements and air emissions, as direct-push rigs are generally smaller than conventional hollow-stem auger rigs.	1) One-time collection of samples. 2) Not well suited for coarse-grained soil types.	Pitkin et al., 1994 US EPA, 1997 US EPA, 2004 US EPA, 2005

(*Continued*)

Exhibit 3-1. Continued

Technology	Sustainable Practices	Applications	Advantages	Limitations	Technical References
Nonpumping groundwater-sampling devices	Use of passive-diffusion or grab-type samplers for collection of groundwater samples.	Deployed in existing monitoring wells.	1) Minimizes IDW and energy consumption associated with purge sampling. 2) Often correlates well with data collected using conventional sampling techniques. 3) Can be used to collect samples for any laboratory analytical tests.	1) Some devices may be limited to specific contaminant type (e.g., VOCs). 2) Some devices cannot be reused. 3) Regulatory barriers exist for some devices.	ITRC, 2006
Screening tools	Use of field screening qualitative methods for a preliminary assessment of contamination (e.g., handheld organic vapor analyzers, such as flame ionization detector or photoionization detector, ultraviolet fluorescence, dye tests, and the Gore-Sorber® interface probe).	Ideal for screening soil and groundwater samples to generate depth profiles of relative contaminant concentrations or detection of NAPL. Some devices are useful for air monitoring and prescreening confirmation samples during excavation.	1) Minimizes both IDW and the number of samples analyzed by a laboratory. 2) Minimizes soil sample transportation energy requirements and air emissions. 3) Inexpensive to rent and easy to use. 4) A relative quick method for assessing the presence of contaminants.	1) Some devices cannot be reused. 2) Regulatory barriers exist for some devices. 3) Results in qualitative, not quantitative data.	US EPA, 1997

(*Continued*)

Exhibit 3-1. Continued

Technology	Sustainable Practices	Applications	Advantages	Limitations	Technical References
Geophysical methods	Tools for screening sites for metallic objects, subsurface features, or changes in soil bulk density (e.g., magnetometer surveys, frequency domain electromagnetics, time domain electromagnetics, ground-penetrating radar, surface resistivity, shallow seismic reflection, refraction).	1) Alluvial and glacial environments are ideal. 2) Some technologies (e.g., GPR) do not work well in fine-grained soils.	1) Use of nonintrusive and portable tools that can be rapidly deployed. 2) Can be partially used in lieu of conventional tools (e.g. hollow-stem auger rig) that are more energy-intensive, and generate IDW and air emissions.	Background magnetic field or aboveground metallic features can interfere with data interpretation.	US EPA, 2000
Direct-push sensor technologies	Tools for characterizing lithology, contaminant distribution, and subsurface hydraulic properties (e.g., cone penetrometer test, soil-conductivity probe, membrane interface probe, laser-induced fluorescence, hydraulic profiling tools).	For use in unconsolidated soils to depths up to 150 feet depending on conditions and advancement method.	1) Proven technologies that can be deployed rapidly and efficiently to characterize the subsurface. 2) Minimizes IDW, air emissions, and energy consumption. 3) Minimizes rig mobilization/demobilization energy requirements and air emissions, as some rigs are smaller than conventional hollow-stem auger rigs.	Some sensors can be influenced by field conditions that may bias the interpretation of the data.	Griffin and Watson, 2002 Wilson et al., 2005

(*Continued*)

Exhibit 3-1. Continued

Technology	Sustainable Practices	Applications	Advantages	Limitations	Technical References
"Beyond the Fence Line" Technologies for Site Assessment					
Recycled materials	Use of recycled materials.	Materials for monitoring-well installation and soil and groundwater sampling, as well as screening tools.	Minimizes IDW and energy consumption associated with fabrication of new materials.	May compromise sample integrity if used for soil and groundwater sampling without proper decontamination procedures and practices.	US EPA, 2008b
Biofuels	Use of biofuels for transportation.	Personnel, materials, and equipment can be transported by trucks and other vehicles that use biofuels.	Minimizes transportation energy requirements and air emissions of trucks and other vehicles.	Limited availability of zero-emission biofuel vehicles and of biofuel fueling stations.	US EPA, 2008b

 Remediation DOI: 10.1002.rem

tool is also presented. Some methods are qualitative but yield a relative ranking and are considered a hybrid; other methods are quantitative and provide numeric results. Exhibit 3-2 summarizes the outputs of the tools described.

When assessing sustainable practices in remediation, many questions arise. Should sustainability be included as an additional balancing criterion? How should parameters such as social, economic, and environmental impacts be measured? As discussed in Section 2.3.2, remediation designs in the CERCLA and RCRA programs must meet threshold criteria and then weigh balancing criteria. Under a new sustainability paradigm, several metrics may become part of the remediation process (e.g., carbon dioxide emissions, energy consumption, and resource service for land and/or groundwater). Additional measures that might also be considered are local community impacts, such as the noise, traffic, and other nuisances generated during a remediation effort; quantification of the occupational safety risks associated with a remediation activity; and economic cost versus benefit. Where should the boundary for the analysis be drawn? Should it be the property line of the remediated site, a specific radial distance from the contaminated site, or should it include global impacts? Should the analysis account for these primary impacts alone or should secondary impacts be considered? The capability to estimate these impacts with a user-friendly, automated tool would provide remediation professionals with a way to consider the sustainability of various remediation technologies while circumventing time-consuming ad hoc calculations of these parameters.

When assessing sustainable practices in remediation, many questions arise. Should sustainability be included as an additional balancing criterion? How should parameters such as social, economic, and environmental impacts be measured?

3.2.1 Life-Cycle Assessment and Methodology for Remediation

Life-cycle assessment (LCA) is a standardized method to determine the environmental and human health impacts of products or services (International Organization for Standardization [ISO] 14040 series). To date, LCA has been used primarily by businesses to benchmark operations or evaluate and compare products or alternative processes. LCA is increasingly being used at a strategic level for business development, policy development, and education. In ISO 14040, LCA is defined as the "compilation and evaluation of the inputs, outputs, and potential environmental impacts of a system throughout its life cycle." A product's life cycle is generally broken down into stages, including transportation. Activities, such as remediation, are made up of similar steps, such as raw materials extraction and processing; intermediate materials production and consumption; processes and activities on-site, including maintenance; and end-of-life management, including reuse, recycling, and disposal.

Life-cycle thinking helps remediation professionals recognize how selections are one part of a whole system so trade-offs can be balanced and positively impact the economy, the environment, and society. The environmental footprint of remediation activities is larger than the work performed at a site because the materials and energy consumed create impacts elsewhere. In addition, these external impacts or externalities are not included in decision making for a site, but the costs of these external impacts ultimately become a burden to society. Cleanup activities may exert indirect impacts on humans and the environment, which may or may not be directly associated with site activities.

Life-Cycle Perspective in Remediation—*the life-cycle perspective includes quantification of the environmental burden of every step of a project.*

Remediation DOI: 10.1002.rem

Exhibit 3-2. Output of quantitative sustainability tools—Metrics

Tool Name	Approach	Environmental Outputs	Social Outputs	Economic Outputs
Life-Cycle Assessment (general)	Quantitative	Impacts of resource consumption, energy use, transportation emissions, and fuel production	Impact of emissions on regional and global health	
AFCEE Sustainable Remediation Tool (GSI Environmental)	Quantitative	Carbon dioxide emissions, total energy consumed, and change in resource service	Safety/accident risk	Technology cost
Net Environmental Benefit Analysis	Quantify and compare ecosystem service impacts	Evaluates existence and aesthetic value of ecosystems, preservation of biodiversity, habitat for threatened/endangered species, and human recreational use	Risk reduction	Cost and natural resource service benefits and losses
URS/DuPont Sustainability Assessment Tool	Quantitative	Assessment of greenhouse gas production, energy usage, resource usage, and utilization of consumable products to determine carbon footprint/tons of CO_2 equivalents	90 social outputs	–
GolderSET-SR-CN Sustainability Tool	Hybrid: semi-quantitative and qualitative	Assessment of soil, sediment, groundwater, and surface water quality; product removal; water consumption; wildlife and flora conservation; drinking water supply conservation; off-site migration prevention; greenhouse gas emissions; energy conservation; solid residual matter management; site contaminant management; and hazardous waste management	Assessment of impact on local resident safety and quality of life; worker safety; limited duration of work; benefits for contractor staff; beneficial use for local community; employee skill development; local job creation and diversity; competitive advantage through innovation; response to social sensitivity; and standards, laws, and regulations	Assessment of initial capital cost moderation; low annual O&M cost; prevention of potential litigation; potential grants or subsidies; environmental liabilities reduction; train service reliability and performance; donations to the community; economic advantages for the local community; reliability (moderate maintenance and repair); economic advantage of more effective technology; and technological uncertainty management

(Continued)

Exhibit 3-2. Continued

Tool Name	Approach	Environmental Outputs	Social Outputs	Economic Outputs
Minnesota Pollution Control Agency (MPCA) Green Practices for Business, Site Development, and Site Cleanups: A Toolkit	Qualitative	Assessment of reasonableness of remediation/restoration options through decision-tree evaluation and case studies	Assessment of community acceptability	Technology cost
The REC Decision Support System for Comparing Soil Remediation Alternatives (Dutch Research Programme for *In Situ* Bioremediation)	Comparison of soil remediation technologies	Environmental merit	Risk reduction	Cost
Shell Cost-Benefit Analysis (United Kingdom)	Quantitative	Impacts of groundwater remediation (monetization of impacts)	Monetization of risk/benefits	Technology cost
Swedish Hållbar Sanering cost-benefit analysis/life-cycle analysis model	Quantitative	Primary, secondary, and tertiary effects of contamination/remediation as in resource use, climate change, acidification, eutrophication, ozone formation, human toxicity, and ecotoxicity	Risk/socioeconomic cost of secondary emissions (NO_x, SO_2, VOC, particulate matter)	Cost of cleanup
British Electric National Grid (developing a toolkit that will be available to public)	Hybrid	Carbon dioxide emissions, waste reuse, levels of noise, dust, vibration, and odor	Deaths/injuries	Cost

(*Continued*)

Exhibit 3-2. Continued

Tool Name	Approach	Environmental Outputs	Social Outputs	Economic Outputs
Danish National Railway Agency's Model to Calculate Environmental Costs and Benefits	Quantitative evaluation of cost/benefit	Consumption of crude oil, hard coal, natural gas, brown coal, aluminum, iron, copper, manganese, nickel, sand/gravel, and water Potential effects of global warming, ozone depletion, acidification, photochemical ozone formation, nutrient enrichment, persistent toxicity, human toxicity, ecotoxicity, bulk waste, hazardous waste, nuclear waste, slag, and ash Potential environmental benefits: reduction in persistent toxicity, reduction in ecotoxicity	Reduction in human toxicity from air and groundwater contaminants	–
California DTSC Green Remediation Matrix	Qualitative matrix	17 items within categories of substance and thermal releases, resource depletion, and physical disturbances	–	–
Ontario Life-Cycle Framework	Qualitative matrix and LCA	Matrix includes 22 items within pollution, disturbance, and depletion categories. LCA includes groundwater protection, solid waste burden, contaminant fate and toxicity, land use, and residual toxicity	–	–
Cadotte et al. (2007) LCA study	LCA	Groundwater protection, ozone depletion, acidification, eutrophication, photochemical smog, and ecotoxicity	Human health	–

(*Continued*)

Exhibit 3-2. Continued

Tool Name	Approach	Environmental Outputs	Social Outputs	Economic Outputs
Volkwein et al. (1999) LCA study	LCA	16 impact categories	–	–
Godin et al. (2004) LCA study	LCA	12 impact categories	–	–
Toffoletto et al. (2005) LCA study	LCA	12 impact categories	–	–
Lesage et al. (2007) LCA model	LCA	Four combined categories of human health, ecosystem quality, climate change, and resources	Human health	–
Illinois EPA/AECOM	Qualitative	Identification of benefits of remediation projects in terms of air, water, land, and energy; assessment of cleanup options for minimizing pollution	Identifies potential regulatory, administrative, and operational barriers to remediation	Assessment of maximum efficiency of cleanup options
Sustainable Development Principles Worksheet (Chevron Superfund Site)	Hybrid	Waste minimization, recycling	–	Assessment of land use and quality of business environment to enhance economic opportunities

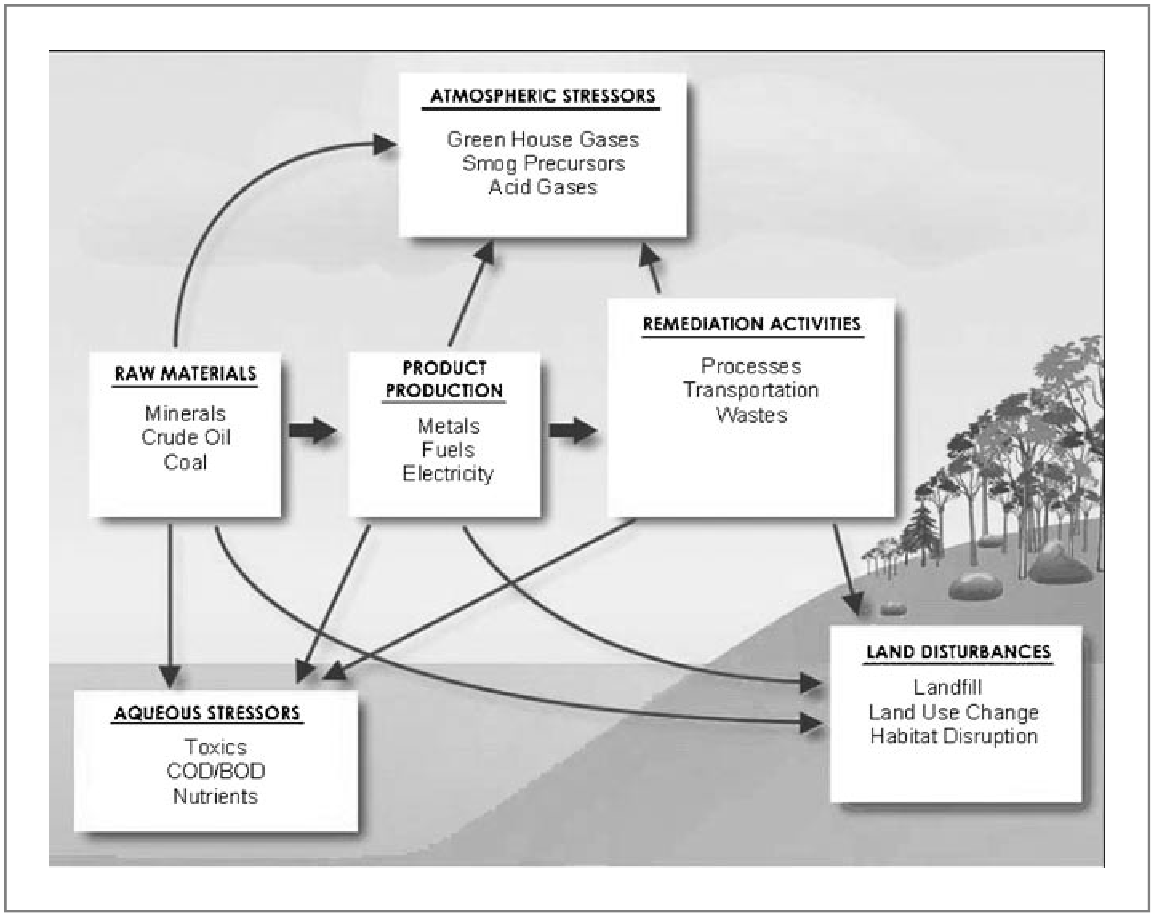

Exhibit 3-3. Life-cycle framework

LCA can provide the information on specific environmental impacts and burdens that occur due to on-site and off-site activities. For remediation, this relates primarily to consuming resources and energy on-site, but also includes any environmental impacts outside of the contaminated property boundaries. For example, one could consider not only the transportation emission impacts, but also the fuel production impacts and the regional health and global impacts of the emissions.

In general, LCA can be used within remediation in several ways: (1) to provide benchmarking for existing systems, (2) to identify retrospectively opportunities to decrease impacts in future cleanups, (3) to identify retrospectively where specific improvements would be most advantageous, and (4) to compare different remediation options during the technology selection process. Exhibit 3-3 shows a life-cycle framework. The methodology follows life-cycle management principles that have been developed as an integrated concept for managing the total life cycle of products and services toward more sustainable consumption and production patterns. A qualitative matrix evaluation can be used in lieu of full LCA as a screening tool to reveal broader impacts.

Using LCA to assess the potential environmental and human health impacts associated with a product, process, or service could involve the following, based on ISO 14044 guidelines: compiling an inventory of energy and material inputs and environmental releases, evaluating the environmental impacts associated with identified inputs and releases, and interpreting the results to help make a more informed decision.

3.2.2 LCA Remediation Applications

LCA was applied to remediation before the evolution of sustainable remediation in the United States. A few studies in the literature demonstrate the use and benefits of LCA for remediation. Most have been written following a life-cycle framework that was developed specifically for remediation for the Ontario Ministry of the Environment (Diamond et al., 1998). Suer et al. (2004) provide an excellent overview of these earlier applications. Most LCA applications have occurred at the remedy-selection stage (Cadotte et al., 2007; Godin et al., 2004; Toffoletto et al., 2005), although some have evaluated existing remediation projects (HOH Water Technology A/S et al., 2000; Page et al., 1999; Suer et al., 2004). These and other applications are described below.

> Godin showed that LCA can be used as a screening tool to help identify significant environmental issues for further exploration. The aim of the study was to identify a remediation option that minimizes overall environmental impacts based on a comparative LCA and contaminant groundwater transport modeling.

The Ontario Ministry of Environment framework (Diamond et al., 1998) was used by Page et al. (1999) to examine issues related to broad impacts of site remediation processes and is based on the life-cycle concept outlined in the following discussion. After developing a process-flow diagram and identifying all of the process inputs and outputs, individual inventory items are linked to a potential environmental impacts checklist. This checklist associates the impacts with the physical, chemical, or biological stressors. Each stressor can be ranked by level of concern if sufficient process information is known. At the simplest level, the framework approach helps to identify key areas for improvement or opportunities for reducing burdens. The study describes the extension of the matrix into LCA and includes several methods in a comparative case study.

Volkwein (1999) discussed a tool using streamlined LCA combined with the results of a risk assessment of a contaminated site in Germany. This tool incorporates the secondary impacts of the remediation activities with the primary impacts of the contaminated site. LCA results are presented in 14 impact categories that are normalized to the highest value in each category. These values are called disadvantage factors and make interpretation easier. The last step is to consider the LCA results with the results of a risk assessment for more informed decision making. A case study evaluated three methods, including dig and haul, installation of an asphalt cap, and thermal/biotreatment of oil-contaminated soil. Also included was a sensitivity analysis with some alternatives (e.g., clean diesel, low-soot emissions), as well as an improvement assessment.

Toffoletto et al. (2005) describe a retrospective LCA of *ex situ* bioremediation of diesel-contaminated soil in Quebec. The main objective of the work was to compare the primary and secondary impacts of the biopile treatment life cycle as a function of the duration of treatment and the achievement of regulatory criteria. In this paper, a case study considered petroleum-contaminated soil biotreated on-site versus hauling the soil to a permanent treatment site. The comprehensive work followed the ISO standards and included 11 stages. Results of the study identified several process optimizations to reduce the environmental load of bioremediation treatment. However, as with many studies, data quality limited the conclusions drawn.

Godin et al. (2004) showed that LCA can be used as a screening tool to help identify significant environmental issues for further exploration. The aim of the study was to identify a remediation option that minimizes overall environmental impacts based on a comparative LCA and contaminant groundwater transport modeling. A case study evaluated four options (i.e., dig and haul, excavation and treatment, excavation and incineration in a cement kiln, and leaving the soil in place) for a landfill containing spent-pot lining from aluminum manufacture. One key conclusion was that primary (i.e.,

Remediation DOI: 10.1002.rem

site-specific) data are needed for the LCA because site-specific conditions have a dominant influence on contaminant behavior.

Cadotte et al. (2007) describe the use of LCA for the selection of a remediation method considering treatment time, residual contamination impacts, and remediation method impacts. A case study evaluated *in situ* and *ex situ* methods for a light, nonaqueous-phase liquid (LNAPL) site in Quebec for both soil and groundwater cleanup. The study was comprehensive and showed the value of the LCA methodology in comparing the environmental performance of treatment scenarios. It compared four solutions spanning 8 years to more than 300 years and compiled both the primary (from the residual contamination) and secondary (from the remediation activity) impacts. The effort helped to show the best combination of technologies from the three soil and four groundwater methods studied.

Lesage et al. (2007) describe the assessment of brownfield rehabilitation considering both the LCA approach for evaluating impacts of the site cleanup and the ultimate reuse of the property. This expansion is based on consequential LCA because it considers the site reuse impacts. Partial economic models are used to quantify the benefits of reintegrating a site back into the economy. A case study showed that the impacts of the site reuse choice may dominate the cleanup method impacts and that reuse should be considered as part of the overall evaluation.

3.2.3 Net Environmental Benefit Analysis in Remediation

Net environmental benefit analysis (NEBA) is another approach that can be used to study the impact of remediation on resources (for a more detailed discussion of this topic, see Efroymson et al., 2004). It is defined as a risk-benefit analysis applied to environmental management options. NEBA serves to quantify and compare ecosystem service impacts that occur as a result of an environmental management option, such as remediation or redevelopment. These ecosystem service impacts are compared with changes to cost and predicted changes in risk to determine the net environmental benefit of each alternative.

The improvement in natural resource services resulting from a remedy, compared to the baseline, is viewed as the net service benefit of the remedy.

Ecosystem services can be viewed as ecological use, passive use, or human (e.g., recreational) use of the resource. These uses result from a flow of services over time from the natural resource. Some common ecological services of a natural resource are nesting or breeding areas and soil and sediment stabilization. Habitat equivalency analysis is used to quantify ecological services and is reported in service-acres-years (Favara et al., 2008). Passive uses include the existence and aesthetic value of the ecosystem, preservation of biodiversity, and potential habitat for threatened and endangered species. These uses can be quantified using contingent valuation reported in U.S. dollars (or other currency). Human uses might be recreational (e.g., swimming and bird watching) or commercial (e.g., fishing). These services are quantified using economic models, such as revealed preference methods (e.g., travel cost, Random Utility) or benefits transfer methods that can show the value in user days and local currency.

The improvement or diminishment of these services as a result of remediation is quantified and compared with respect to risk reduction and cost. The improvement in natural resource services resulting from a remedy, compared to the baseline, is viewed as the net service benefit of the remedy. In cases where a remedy results in a decrease in service value (compared to the baseline), the net service benefit of the remedy is negative.

 Remediation DOI: 10.1002.rem

In the case of remediation, comparing the net service benefits between various alternatives allows decision makers to determine where break points occur between risk, financial costs, and natural resource service benefits for the various remedial alternatives.

NEBA approaches are used by several state environmental regulatory agencies. The Texas Commission on Environmental Quality, the State of Florida Department of Environmental Protection, and the Washington State Model Toxics Control Act include NEBA-related methodologies (Efroymson et al., 2004).

One of the great advantages of conducting a cost-benefit analysis is that it helps to understand the benefit that is being achieved (e.g., improvement in aquifer quality) and weigh the benefit against the cost (e.g., equipment cost, carbon dioxide emissions) in a common unit of measure.

3.2.4 Cost-Benefit Analysis

In the United Kingdom, the Environment Agency has developed guidance on how to assess the costs and benefits of soil and groundwater remediation after the threshold criterion of health protection has been achieved. Having guidance that considers the economic ramifications of remediation has made the extension to considering sustainability parameters more straightforward than in the United States, where remediation is often conducted to reach a numeric treatment goal. The cost-benefit approach compares possible remedial solutions by monetizing risk and damage avoided, or, in other words, costs and benefits.

In a cost-benefit analysis, the costs and benefits of sustainability factors (i.e., environmental, economic, and social) are characterized as private, meaning they impact the site owner, or external, meaning they impact society. The remedial solutions accrue different benefits and risks, and the overall net benefit is calculated. A sensitivity analysis is then undertaken to assess the effect of variations in the input parameters to the outcome of the cost-benefit analysis. The sensitivity analysis may reveal that one approach is always the optimal solution or it may identify which parameters are the most influential and where to focus additional effort to refine uncertainty. The apportionment of costs and benefits between different stakeholders is also a factor to be considered in the final decision. One of the great advantages of conducting a cost-benefit analysis is that it helps to understand the benefit that is being achieved (e.g., improvement in aquifer quality) and weigh the benefit against the cost (e.g., equipment cost, carbon dioxide emissions) in a common unit of measure. A cost-benefit analysis case study is presented in Exhibit 3-4.

3.2.5 Quantitative Assessment Tools

The remediation community has been developing new tools to assess the impact of remediation technologies on the environment, society, and economics. Some of the organizations that have developed tools are the Air Force Center for Engineering and the Environment (AFCEE), DuPont, the Dutch Research Programme for *In Situ* Bioremediation, the Danish National Railway Agency, the British Electric National Grid, and the Swedish Riksdag. The tools developed by these organizations are described briefly in the paragraphs that follow, and Exhibit 3-2 summarizes the outputs of the tools described. In addition, many organizations, such as BP, Good EarthKeeping Organization, and Haley & Aldrich have developed carbon footprint calculator tools or assessed sustainability parameters at remediation sites. Tools for calculating carbon dioxide emissions are numerous and, therefore, are only generally discussed in the paragraphs that follow.

 Remediation DOI: 10.1002.rem

Exhibit 3-4. Cost-benefit analysis case study

In the United Kingdom, the cost-benefit analysis approach was used to incorporate sustainability principles into the remedial decision-making process at a service station site. Pump-and-treat and multiphase extraction technologies had been used to remove mobile light nonaqueous-phase liquid (LNAPL) at the site. The intent of the study was to determine whether further remedial actions were merited to achieve additional polishing of groundwater quality. The only source-pathway-receptor linkage that was complete was impact to groundwater. Groundwater is not currently used as a drinking source, but theoretically could be used for this purpose in the future. The net present values of the costs and benefits of several options were compared. Options considered in the cost-benefit analysis were as follows:

- Source removal
  - slow-release oxygen technique
  - total fluids extraction
  - *in situ* chemical oxidation
  - dual-phase extraction
  - air sparging and soil vapor extraction
  - excavation and landfill disposal
- Plume interception
  - air sparging barrier
  - off-site slow release oxygen technique
  - off-site groundwater interception by a reactive wall
- Receptor management (i.e., end-of-pipe groundwater treatment from a hypothetical future water-supply well)
- Monitored natural attenuation
- No further action

The base-case analysis showed no net benefit of any of the options considered. The sensitivity analysis confirmed this finding for the low-cost case. For the case where conservative assumptions were made about the possible remediation benefits, a low-cost, low-energy-intensive remedial option (e.g., a slow-release oxygen technique) may be appropriate. This analysis will be used as the basis for discussion with the regulatory agency for future site management.

The AFCEE has developed a Sustainable Remediation Tool to integrate sustainable concepts into remedy selection and optimize remediation technology systems already in place. The tool allows users to estimate sustainability metrics for specific technologies (e.g., excavation, soil vapor extraction, pump-and-treat, and enhanced *in situ* biodegradation). The tool is built on the Microsoft Excel platform and is structured into RBCA toolkit-type tiers (GSI Environmental Inc., 2008). Tier 1 calculations are based on rules of thumb that are widely used in the environmental remediation industry. Tier 2 calculations are more detailed and incorporate more site-specific factors. The tool is composed of three main sections: input, technology, and output screens. For each technology, the tool calculates design elements and materials and consumables needed for each major component, allowing the user to adjust values and then feed the totals into the output metrics calculations. A technology can also be assessed as to capital impacts, operation and maintenance impacts, or both. The tool also looks at the lifetime of the system and different scenarios. Sustainability metrics within the tool are carbon dioxide emissions, economic cost, energy consumption, safety/accident risk, and change in resource service from land and/or groundwater. The user has the option to view these metrics in nonnormalized units, normalized units, or both. Other innovative features of the tool include the use of scenario planning and a consensus-building virtual meeting room. The Sustainable Remediation Tool is being implemented in the Air Force through the remediation process optimization program and is being tested and evaluated by the US EPA. Additional information about the tool is available at http://www.afcee.af.mil/resources/technologytransfer/programsandinitiatives/sustainableremediation/index.asp.

The Sustainable Remediation Tool is being implemented in the Air Force through the remediation process optimization program and is being tested and evaluated by the US EPA.

DuPont has developed Microsoft Excel–based spreadsheets for a number of remedial technologies, including pump-and-treat, excavation, zero-valent iron/clay mixing, and soil vapor extraction. The evaluation begins at the site boundary, meaning that a full LCA is not included in the assessment of impacts. The spreadsheets are similar to the life-cycle method described previously in that the assessments are built from tasks, or activities, such as mobilization/demobilization, system construction, system startup, system decommissioning, and operation and maintenance. Occupational risk is considered as an impact, and the burden of consumed materials, such as steel, polyvinyl chloride pipe, or high-density polyethylene sheeting, is included to determine the holistic impact of a remedial option. Air emissions, other than the production of greenhouse gas, can be estimated. Energy usage, resource usage (water and land), occupational risk, community impacts (qualitatively), and utilization of consumable products is assessed, and these activities (where possible) are used to estimate the carbon footprint, or tons of carbon dioxide equivalents, produced. In some cases, the tons of carbon dioxide are compared to the mass of contaminant removed. DuPont has been able to use the tool for remedy selection at several sites.

The Dutch Research Programme for *In Situ* Bioremediation developed a tool to analyze and support the choice of the most efficient and effective strategy for soil remediation. The tool is called the REC Decision Support System for Comparing Soil Remediation Alternatives, with "REC" meaning risk reduction, environmental merit, and costs (Beinat, 1997). From the Dutch perspective, soil remediation has long focused on reducing contaminant concentrations to regulatory standards in the shortest time. However, technical and cost limitations often prevent this goal from being reached. This tool seeks to consider the full range of financial and environmental costs and benefits and to balance these considerations on both local and global scales. The system considers the indices of risk reduction, environmental merit, and costs, which can be calculated in spreadsheets. The output is the set of three indices that summarize the overall performance of each remediation option. In this way, the tool allows users to systematically consider the pros and cons of each technology or method.

The Danish National Railway Agency's Model to Calculate Environmental Costs and Benefits is a tool used to calculate the environmental costs and the anticipated environmental benefits of remediation so that these factors can be incorporated along with function, economy, and time to support remedy decision making (HOH Water Technology A/S et al., 2000). This Microsoft Excel–based tool is highly detailed and comprehensive and contains both quantitative calculation worksheets and sections where written narratives and supporting information for the project can be documented. The data output section is divided into the estimation of environmental costs and benefits. Because the entry data in the model was derived from six specific remediation projects, the user can enter site-specific data for resource consumption as well as for discharges. Additionally, the user can select absolute, normalized (in human equivalents), or weighted (relative to the horizon of supply and to society's targeted reduction goals) consumption of resources.

Remediation DOI: 10.1002.rem

The British Electric National Grid is refining a spreadsheet-based tool and has commissioned Worley Parsons Komex to execute the project. Sustainability is one of the criteria assessed during a remedial options appraisal. In the current iteration of the spreadsheet tool, the analysis starts with a full process diagram that considers the remedial options. An input screen then addresses issues, such as selection of off-site facilities, transportation distances, and treatment volumes. Time frames for activity are considered throughout the options. An output screen then generates qualitative and quantitative data for parameters, such as local impacts (e.g., noise and vibration might rank high while dust impacts rank medium and odor ranks low). Safety features are also generated, with the focus on deaths and injuries from an actuarial perspective. Finally, regional impacts are assessed with regard to emissions and particulates associated with each operation. Long-term plans for the model include refinement and the integration of additional remedial options as necessary. Additional information is provided at http://www.claire.co.uk/index.php?option=com_content&task=view&id=182&Itemid=78&limit=1&limitstart=6.

The Swedish Riksdag has implemented a directive with an overarching environmental quality objective of having "a nontoxic environment" in Sweden. Sustainable remediation is incorporated into one of the 16 pillars that define the objective, and the Environmental Objectives Council reports to the Government on the progress made in this regard (Swedish Environmental Objectives Council, 2007). The most detailed review of sustainable remediation practices has focused on soil remediation and controlling the potential negative effects during remediation processes. Soil remediation has been studied with a life-cycle perspective in terms of risk, environmental performance, and socioeconomic impacts. These efforts have led to a modeling process that is used to support decision making at contaminated sites. The model is intended for use in situations in which remediation is necessary and an enhanced risk analysis platform is present. Environmental performance is evaluated in a standard LCA. In this analysis, the impact categories are resource use, climate change, acidification, eutrophication, ozone formation, human toxicity, and ecotoxicity. Socioeconomic evaluations consider the cleanup cost and the socioeconomic costs due to secondary emissions. The model was tested in a case study, which is summarized in Exhibit 3-5 (Andersson et al., 2008).

Socioeconomic evaluations consider the cleanup cost and the socioeconomic costs due to secondary emissions.

Finally, a number of engineering consulting firms, as well as governmental agencies, have developed tools that measure the impacts of various remediation practices on the production of carbon dioxide. In general, the tools have as inputs the consumption of fuel and electricity at a site during remediation system operation, the types and duration of drilling activities, materials used, and mileage driven. Then, these numbers are converted to carbon dioxide with accepted conversion factors such as those provided by the U.S. Department of Energy under the Voluntary Reporting of Greenhouse Gases Program fuel and energy source codes and emission coefficients. Additional information about this program is available at http://www.eia.doe.gov/oiaf/1605/coefficients.html. Some other protocols are the Greenhouse Gas Protocol developed by the World Business Council and the World Resources Institute and the General Reporting Protocol by The Climate Registry.

3.2.6 Hybrid and Qualitative Tools

Hybrid and qualitative tools are also being developed to screen the impact of remediation technologies on the environment, society, and economics. The following organizations

Exhibit 3-5. Case study of the Swedish Riksdag cost-benefit analysis tool

The Swedish Riksdag cost-benefit analysis tool was tested in a case study of remediation of soil contaminated with aliphatics; aromatics; and benzene, toluene, ethylbenzene, and xylenes as would be found at a typical gas station. The remediation alternatives evaluated were composting on-site, composting off-site, and *in situ* aeration. The target groups for the evaluation, as well as the tool prototype, were consultants, entrepreneurs, and decision makers at the Swedish EPA, county administrative boards, and municipalities.

For all three remediation alternatives, four scenarios were compared. The scenarios varied in terms of levels of contamination at the start and end of the remediation. Finally, a simplified tool prototype was developed. The case study showed that environmental performance and socioeconomics can be systematically handled and quantitatively evaluated. The case study cannot, however, support decisions regarding the choice of the area to remediate or the level of residual risk. One important conclusion of the case study was that, in terms of secondary environmental effects, life-cycle costs for cleanup, and socioeconomic costs due to secondary emissions, the selection of the remediation alternative is much more important than the level of residual risk. In general, the differences between *in situ* aeration and composting on-site in terms of secondary environmental effects and costs are small compared to the differences between composting on-site and composting off-site. The secondary contributions to human toxicity and ecotoxicity are larger than the corresponding primary contributions, or, in other words, the impact of the emissions of toxic substances from the remediation process (and its service system) is larger than the impact of leaching soil contaminants during 50 years.

The assessment of secondary environmental impacts shows that, for composting on-site, the largest contribution is from the use of construction machinery. For composting off-site, the largest contribution is from the use of construction machinery and the transportation of contaminated soil to the treatment facility. For *in situ* aeration, the largest contribution is from the production of electricity and fertilizers. For the impact categories of human toxicity and ecotoxicity, significant additional hotspots are as follows: processes upstream in the manufacturing and maintenance of trucks, processes upstream in the manufacturing of construction machinery, fertilizer production, and leaching of soil contaminants during and after remediation (for some of the scenarios).

The socioeconomic costs of the emissions (NO_x, SO_2, VOCs, particulates, and CO_2) caused by the remediation and its service system from a life-cycle perspective vary with the population density in the area where the emissions occur. Higher population density results in higher costs. The cost calculations have been performed for Stockholm, Södertälje, and Laholm (Sweden). In comparison with the life-cycle costs for cleanup, the socioeconomic costs of emissions are small or very small depending on the population density in the area undergoing remediation.

are among those that have developed screening tools: the California Department of Toxic Substances Control, Golder Associates, Chevron, the Illinois EPA, the Minnesota Pollution Control Agency, and the U.S. Army Corps of Engineers. Each tool is described briefly in the paragraphs that follow. Exhibit 3-2 summarizes the outputs of the tools described.

The Green Remediation Team of the California Department of Toxic Substances Control is developing a screening tool based upon a life-cycle approach. The team developed a matrix to consider and rank the material and energy inputs and outputs associated with virtually all elements of a remedy. Based largely upon the work of Diamond et al. (1999), the team selected a qualitative life-cycle management approach.

For Canadian National (CN), Golder Associates customized a sustainability screening tool to assist in remedial project planning. The goal was to use key indicators based on international sustainability standards and to tailor the tool to the company's specific issues,

Remediation DOI: 10.1002.rem

Exhibit 3-6. Customization of Golder Associates tool for Canadian National

Based on Canadian National (CN) requirements with regard to the ease of use and results output, the Golder Sustainability Evaluation Tool for Site Remediation (GolderSET-SR; © Golder Associates Ltd., 2007) platform was selected and customized for CN's needs. The GolderSET-SR is a sustainability screening tool developed using a Microsoft Excel spreadsheet. Currently, the tool includes 14 environmental indicators, 10 societal indicators, and 11 economic indicators and allows for the addition of complementary indicators if needed. Among other things, the indicators take into account the ultimate objective of the project; its eco-efficiency; societal benefits to the workers, the community and corporate image; and the project economic performance in terms of capital and operation and maintenance (O&M) costs, return to the community, and the potential for complementary incomes or litigation awards.

Following the identification, full description, and the grouping of these indicators, a matrix (or evaluation grid) was developed. The matrix was structured based on the potential for the quantitative assessment of some indicators (e.g., greenhouse gas emissions, energy conservation, capital and O&M costs, duration of work, and local job creation) and on the potential for the qualitative assessment of other indicators (e.g., wildlife and flora conservation, worker safety, local residents' safety and quality of life, potential for litigation). Scoring criteria and boundaries were specified for each indicator.

For each option, the weighted average of the indicators was calculated for each group of indicators (i.e., environment, society, and economy) by taking into account the scores and weighting factors attributed to each of the applicable indicators. The average values calculated were displayed for each of the options. Subsequently, the weighted average values of each of the three groups were used to create a triangular representation of their distribution. An option with a triangle of reduced surface area adheres less to the principles of sustainable development than does an option whose triangular representation has a larger surface area. The shape of the triangle also helps to visualize the trends of the different dimensions of sustainable development (e.g., an environmental, social, or economical bias). In general, the favored option will demonstrate the largest, most balanced triangular representation.

The tool was submitted to a sensitivity analysis of uncertainty using Monte Carlo simulation. This simulation was performed to demonstrate the effect that varying indicator scores or weighting factors would have on the interpretation of a remedial option's sustainability. The results of the reliability assessment performed for a pilot project showed that the results of the sustainability analysis can be relied upon because they vary only slightly when parameters vary within the anticipated range of possible values. The tool also allowed CN to identify areas for potential mitigation of negative impacts, such as the potential use of renewable energy to offset high energy consumption for the multiphase extraction remediation alternative.

CN is optimizing the tool through a simplified sensitivity analysis by varying scores or weighting factors for high-impact indicators. CN plans on identifying performance indicators and endpoints to ensure that the remedial technique and sustainability performance is monitored and the ongoing optimization of the selected option.

corporate policy, and operational contexts. The tool is based on a Microsoft Excel spreadsheet and allows decision makers to evaluate the short- and long-term environmental, social, and economic impacts of remedial options in a systematic and balanced fashion. In this way, decision makers are able to better justify and defend the selected option and identify the most critical and sensitive elements that should be closely monitored during the life of the project. Exhibit 3-6 summarizes the customization of this tool.

Chevron is developing a Sustainable Development Principles spreadsheet that is organized into three performance areas (social, environmental, and economic), elements, and principles. Users complete the spreadsheet by including site activities that demonstrate the fulfillment of a principle, thereby documenting sustainable achievements in a specific performance area. For example, in the economic performance area, one element is business environment and one principle is land use. Rather than address contaminated soil using a typical remedial approach such as excavation, users could fashion a remedial alternative that addresses and enhances the land-use principle (e.g., hot spot removal followed by ecological revitalization as a tall grass prairie with a circling bike path). The spreadsheet is being applied to a CERCLA site that is developing remedial alternatives as part of the feasibility study process.

The Illinois EPA is currently integrating the matrix into its voluntary and enforcement-driven assessment and cleanup projects, including projects being implemented by the Illinois EPA and projects being implemented by other public or private entities.

The Illinois EPA retained AECOM Environment to assist in developing a greener cleanup strategy. In this case, "greener cleanup" refers to methods of site remediation that (1) make the actual cleanup more efficient and less polluting and (2) result in a site where development is designed to reduce the environmental impacts of future use. The work culminated in the production of a two-page matrix entitled *Green Cleanups: How to Maximize the Environmental Benefits of Site Remediation*. The matrix is available at http://www.epa.state.il.us/land/greener-cleanups/matrix.pdf. The matrix identifies a variety of greener cleanup activities to be considered across the life cycle of an assessment and remediation project, starting with the site assessment itself, proceeding into the planning and design phase, and culminating in the cleanup phase. The matrix identifies the environmental benefits of each activity in terms of air, water, land, and energy. It also presents a qualitative opinion of each activity's level of difficulty and a qualitative opinion on the cost, schedule, and technical complexity impacts of each activity. The Illinois EPA is currently integrating the matrix into its voluntary and enforcement-driven assessment and cleanup projects, including projects being implemented by the Illinois EPA and projects being implemented by other public or private entities. The next step for the Illinois EPA is to develop a decision tree that applies the matrix to a specific assessment and cleanup program.

The Minnesota Pollution Control Agency staff and stakeholders created an Internet-based interactive toolkit to promote pollution prevention and sustainable remediation. The toolkit expands the definition of pollution prevention beyond the typical reduction, reuse, and recycling to include any activity that has "sustainable or enhanced environmental outcomes." The toolkit introduces and recommends sustainable remediation concepts into the remedial option selection phase. The definition of sustainability is "an approach to problem solving that acknowledges the interconnectivity of environmental, economic, and social decisions, which prevents foreseeable adverse impacts to the ability of future generations to meet their needs." The toolkit includes a decision tree, definitions of pollution prevention and sustainable activities, three remediation scenarios, a checklist of factors to consider, and points of implementation (including performance measures tracking progress and recognition). Additional information about the toolkit is available at http://www.p2pays.org/ref/11/10552.htm.

The U.S. Army Corps of Engineers is developing a tool to incorporate sustainability into the Department of the Army environmental remedy selection and optimization processes. This tool is structured to explain the process by which sustainability can be incorporated into the U.S. Army's environmental remediation projects. At the core of the tool is a decision flow chart that takes the user from initial project planning to project closeout. The flow chart uses existing Army and federal sustainability practices, to the extent practical, adapting construction/deconstruction and optimization Army policy and procedures as necessary to fully incorporate sustainability. A companion technical memorandum includes instructions on completing each step in the flow chart, with checklists included as appropriate. A draft of the tool has been developed and is currently in agency review; a final guidance document is planned for December 2009.

3.3 Performance Monitoring

It would be advantageous for sustainable remediation to take advantage of tools for tracking progress and expressing results. Such performance monitoring can be executed by using a variety of tools. The tools range from simple compilations of data contained in spreadsheets for small sites to complex relational databases for more involved projects. The AFCEE has an Excel-based tool called the Performance Tracking Tool that measures system performance by evaluating contaminant removal by cost over time, compared to stated goals of the effort. The performance is tracked to determine if it will meet the projected cleanup goal in the specified time frame and also shows the cost of contaminant removal over time. The tool is free and covers several technologies.

Sustainable practices demand that, in addition to conventional remediation goals, system performance should be evaluated with respect to environmental, social, and economic design goals. Custom-designed tools have the advantage of catering to specific projects and can be designed to track and analyze sustainability parameters that might be unique to that project. However, processing significant amounts of data can be cumbersome, and custom tools may not be widely applicable to multiple sites.

In this spirit, SURF suggests that performance monitoring be linked with the latest tools in data management. That way, performance could be gauged in real time, as actual results are recorded in an appropriate time series. For example, projections could be made for fuel consumption and operational time, but with the ability to input data during operations, a feedback loop would be established that can help regulate the process more efficiently.

Sustainable practices demand that, in addition to conventional remediation goals, system performance should be evaluated with respect to environmental, social, and economic design goals.

The power of database management tools in reporting results can be compelling. A fuller expression of output can be achieved through the interface of the data and the rich array of graphical expression available in commercial software. The integration of those visual images can be further connected to various geographical information system (GIS) platforms to achieve powerful and useful imagery. This last point is critical in that results need to be conveyed to third parties, and the rich palette in these data management systems can be an important feature in presenting information.

When deciding between a custom-designed spreadsheet solution and a commercial software program, one should consider, among other factors, software availability and cost, the amount of anticipated data, the duration of monitoring programs, and data-sharing needs and/or distribution. Whether the data management system is a simple spreadsheet or a complex GIS-linked database is less important than the ability of the user(s) to efficiently and accurately extract data for analysis and distribute the relevant data to interested parties.

3.4 Summary of Concepts and Practices

It is clear that a foundation has been set for incorporating sustainability into remediation. A core of acceptance and growth now exists among many regulatory entities, site owners, and consultants. There is no lack of concepts and practices for sustainable remediation, as has been abundantly illustrated in this section. The US EPA and several state agencies are engaged in the process at some level. For example, the US EPA addressed remedy implementation in its recent green remediation document (US EPA, 2008b). In addition, the TRIAD approach for site assessment has a number of elements that reflect the core values of waste minimization and rational energy utilization and has the support of regulators vis-à-vis organizations such as the ITRC. And finally, the U.S. Department of Defense, in its Remediation Process Optimization program, has several components that contain sustainability concepts for the operation and maintenance phase of remediation. SURF believes that the next step is to develop consensus on specific approaches and tools and on the consolidation of actual engineering values and the frameworks for analysis, output, and decision making.

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 Remediation DOI: 10.1002.rem

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Paul M. Tornatore, P.E., vice president/senior consultant, has 34 years of process engineering experience. At Haley & Aldrich, he has a multifaceted role specializing in technology transfer, site technical strategy, application/development of advanced remediation processes, and design of treatment systems for control of industrial and emerging contaminants. He is named principal inventor on patents for work with extraction and treatment methods. A graduate of Clarkson University, he held a variety of engineering, operations, and maintenance management positions for a major oil company prior to joining Haley & Aldrich in 1991.

David S. Woodward has more than 24 years of experience in the environmental field, has been with AECOM since 1990, and serves as AECOM Environment's director of remediation technology. He is also serving on the executive and planning committees of the Sustainable Remediation Forum, is actively engaged in the development of several sustainable remediation tools, is a member of the Interstate Technology and Regulatory Council's Green and Sustainable Remediation Team, and is supporting the development of the Wisconsin Initiative for Sustainable Cleanups. He specializes in the application of *in situ* remediation technologies and monitored natural attenuation assessments.

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4.0 IMPEDIMENTS AND BARRIERS

There is a demand for sustainable practices in our society and, by extension, sustainable remediation practices. Despite the demand, a lack of guidance documents, standard procedures and processes, and definitive sources of information make it harder to explain the complex technical issues of sustainable remediation to all stakeholders. As discussed in Section 3.0, different types of tools, performance criteria and metrics exist that may be difficult to validate, and a complex interplay between metrics, measurements, and regulations affects the evaluation and selection of the appropriate remedy. At the same time, there is the perception that an organization is "green washing" to avoid responsibility for remediation or using sustainability to select the least expensive remedial option will negatively impact the organization's reputation. "Green washing" is discussed further in Section 5.0.

With all of this in mind, environmental managers and regulators need to prove the benefits of sustainable remediation to stakeholders. Management will want quantification of the cost and the economic benefit, as well as a prediction of whether a sustainable remedy will protect them from future liability and regulatory enforcement. In addition, management will want to be assured that its actions will be perceived positively by shareholders and customers. In the regulatory arena, there will be resistance to adopting new approaches that are more difficult to evaluate, with benefits that are more difficult to quantify. Training will be necessary to allow regulators to understand how to select the most sustainable remedy. Finally, regulators will need to grapple with how sustainable remediation concepts will be integrated into current laws and regulations.

Clearly, societal, technical, economic, and regulatory and legal impediments and barriers exist to the implementation of sustainable remediation. This section explores the nature of these barriers and impediments and discusses the factors that should be considered when evaluating, designing, or implementing a successful sustainable remediation at a site.

4.1 Societal

"Society" in the context of this section applies to everyone who comprises the economic, social, and industrial culture of which we are a part. Our society has laws, customs, values, regulations, and opinions that affect the choice of, and are affected by, a remedial action. In addition, a society requires remedies that make the environment safer for current and future use and to control or eliminate risks to human health and the environment. However, some remedial actions may not significantly reduce the threats to human health and the environment, may result in expenditures of resources that could have been used to provide more tangible societal benefits, and may result in different impacts that pose a greater and different threat than the original risk posed by the contamination being remediated. Those communities in proximity to a remediation site are impacted to a greater extent than those at a distance and, therefore, will often want more input during the remedy selection process. Yet small decisions locally can add up to large consequences globally. Many opportunities exist to achieve a balance between the local and distant impacts of a remedy on our society, including the following:

- development of laws and regulations that require the remediation of sites that have the highest relative threat to human health or the environment;

Remediation DOI: 10.1002.rem

- issuance of guidance to help administrators implement the regulations appropriately;
- development of health and safety regulations to protect workers during remedy implementation; and
- electing representatives who truly believe in establishing and enforcing our environmental, health, and safety protection standards.

At the most basic level, society affects remedy selection by communicating its collective values to those who are responsible for selecting and implementing remedies. Our society places a high value on environmental protection and quality of life. It values reliability and fears risk. It values remedial solutions that have long-term permanence, tending to focus on the permanence and reliability of a solution over the cost of the solution. Society values elected officials who are committed to the quality of the environment; therefore, candidates at all levels are often scrutinized for their environmental record and philosophy. Society values a high degree of confidence in a remedy before it concurs with the approach, and society values certainty. For this reason and because segments of society can sometimes be suspicious of a corporation's motivations for proposing innovative approaches, society often imposes barriers to the approval of remedial designs or approaches that are innovative or not yet proven. Society is engaged in the remedy-selection process through the following:

- Stakeholder groups—For significantly large remediation projects, stakeholder groups (public, private, responsible parties, government, legal, aboriginal, or advocacy groups that will be affected or interested in the remedial outcome) are typically formed to provide a forum for obtaining and communicating societal concerns about a remedy.
- Public elections—Elections represent a significant and important opportunity for the public to voice its opinion on a range of issues, including the priority that should be given to protection of the environment and sustainability.
- Access to regulators—Regulators are generally required to be accessible to the public so that the public can provide comments, concerns, or other input regarding a site or its remedy. This access provides society with an important opportunity to stay engaged in the remedy-selection and remedy-implementation process.
- Public access to corporate records—Through the Emergency Planning and Community Right-to-Know Act reporting requirements and the associated Toxic Release Inventory established by the US EPA, the public has access to corporate records of chemical emissions and waste-disposal activities.

Although the above process engages society, there are many barriers that impede societal acceptance of sustainable remedies:

- Knowledge of sustainability principles—As society's knowledge of sustainability and its importance has increased over the past several years, the value that society places on sustainability has increased. However, society is not generally aware of sustainable remediation principles.
- An established process for remedy selection—Currently, a well-defined remedy-selection process exists that regulators have been implementing, and society at large understands that impedes the acceptance of new ways to evaluate the sustainable concepts into remedy evaluations and acceptance.

- Knowledge of the reliability of sustainable remedies—Very little literature exists on sustainable remedies, and few validated, successful sustainable remedies have been documented.
- Understanding cost-benefit remedies vs. other societal risks or goals—There is little appreciation, acceptance, or concurrence of how to balance the level of protection of human health and the environment with other societal risks or goals to achieve the triple bottom line. As a result, absolute restoration is often selected as the remedy instead of holistic remedies that encompass practical and achievable cleanup levels. It is often difficult to communicate comparisons of remediation risks to everyday-life risks because remediation risks are not always fully understood. For example, it is difficult to compare the risk to life from traffic accidents associated with implementing a remedy versus the risk of the unremediated site in and of itself. The precautionary principle is a natural default position when risks are not fully understood but may lead to remedies that are overly excessive and can prevent the consideration of alternative, more sustainable remedies.

There is little appreciation, acceptance, or concurrence of how to balance the level of protection of human health and the environment with other societal risks or goals to achieve the triple bottom line.

To overcome societal barriers to sustainable remediation, education is needed. Recommended areas for education are summarized below.

- Sustainable remedy examples—Case studies provide a valuable demonstration of the validity of sustainable remedies and, therefore, can help to overcome societal barriers to sustainable remediation. SURF has compiled a comprehensive case study documenting the sustainable remediation process and its costs and benefits (see Section 6.0).
- Decision process for selection of sustainable remedies—Developing a methodology for evaluating the sustainability of remedies can help to overcome societal barriers by providing stakeholders with quantitative metrics and decision methodologies for remedy selection. Well-defined processes build trust and motivation for considering innovative approaches.
- Guidance for sustainable remediation design and implementation—Remediation stakeholders need guidance on how to develop and implement sustainable remedial designs. Such guidance is an important opportunity for educating society on the benefits of sustainable remediation. Guidance can also promote the acceptance of sustainable remediation among regulators, who will be assured of the validity and appropriateness of a sustainable approach.

4.2 Technical

Society embraces new and innovative technologies, concepts, approaches, or practices only after it understands them and the benefit they provide. The sustainable remediation concept is no exception. Sustainable remediation is an innovative approach for which a clear and concise framework is required. A framework that guides the evaluation, application, measurement, and validation of sustainable remediation must rest upon a good foundation. The foundation of this framework must consist of well-defined criteria, without which the practice of sustainable remediation would be difficult to justify.

A sustainable remediation framework consists of the following technical elements: (1) definition, (2) metrics, (3) guidance, (4) resources, and (5) validation. In the first of

Remediation DOI: 10.1002.rem

these five elements, sustainable remediation must be clearly defined in an easily understood manner. Clear definition is important to ensuring the uniform understanding of the concept so that it is not misinterpreted and misused. In addition, a clear definition builds trust and acceptance of the concept as it is developed and deployed. A clear definition also aids in the selection of appropriate tools and measurable metrics. These two elements of sustainable remediation are discussed in Sections 1.0, 3.0, and 5.0 and will therefore not be repeated herein. However, this section discusses issues associated with these and other key elements that hinder the integration of sustainable remediation practices.

4.2.1 Guidance

The lack of established technical guidance is a key barrier to integrating sustainability into site remediation and to its acceptance by all stakeholders. No known technical consensus guidance or manuals are available that outline how to integrate sustainability into site remediation. This lack of guidance impedes the training of remediation industry stakeholders on the practice of sustainable remediation. Extant literature on possible procedures and approaches have not been compiled, compared, and evaluated. For example, Section 3.0 shows the myriad of approaches across the globe for identifying and incorporating sustainability metrics into site remediation decisions. No uniformity or justification of the appropriate metrics is apparent. In addition, significant differences occur in the detail of how various metrics are evaluated (e.g., quantitative vs. qualitative), weighted versus other criteria. Differences also exist between the various approaches on the use of LCA to assess environmental impacts from material and energy consumption.

The lack of technical guidance and protocols makes the comparison of sustainable remedies between sites quite difficult. Sustainable remediation evaluations will not appear to yield robust decisions unless comparable metrics and approaches exist. Unless sustainability is part of corporate policy, site owners may not consider incurring the additional expenditure of evaluating sustainability for a site-remediation project with unknown or uncertain results. Furthermore, without published supporting guidance, remediation practitioners may have difficulty convincing the site owners and regulators of the technical merits and feasibility of integrating sustainability into site remediation.

The lack of established technical guidance is a key barrier to integrating sustainability into site remediation and to its acceptance by all stakeholders.

Of utmost importance to the development of a consistent and comparable sustainable remediation practice is the standardization of sustainability metrics to a meaningful level (i.e., impacts on or benefits to air, land, water, ecosystems, and health and safety). Metrics also should be evaluated within a logical framework (e.g., decision trees/scoring systems) that is integrated within the remedy-selection process and that allows comparison of the sustainability of various remedial alternatives and their ability to meet regulatory and other stakeholders' objectives. For practices related to remedial design, construction, and operation, other frameworks such as the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Green Building Rating System could be referenced to provide the appropriate guidance.

4.2.2 Resources

Although a considerable and growing body of information on sustainability exists (see Section 2.0), the lack of a unified and agreed-upon resource (i.e., knowledge base) is a barrier. Searching for the right information and justifying its validity for use from scattered sources can be a daunting and time-consuming task. The additional time required and the budget constraints of many site-remediation projects could render this task unappealing, making this burden a barrier to integrating sustainability into remediation.

Not all information is created equal, and there can be concerns about the validity of the information or tools used to evaluate sustainable remediation. For example, the following factors are unknown: (1) to what extent LCA should be used to determine the environmental impacts of a remedial action, (2) how greenhouse gas emissions from treatment equipment should be included in the LCA to evaluate air-quality impacts, (3) how pollutants and greenhouse gas emissions associated with the production of materials for use in a remedy should be evaluated, and (4) how far back along the supply chain the evaluation should be taken. Attempting to determine these boundaries could prove to be an endless effort that may deter many remediation stakeholders—and, in particular, responsible parties—from considering sustainable remedies.

The consolidation and validation of tools and references and the compilation of data used to evaluate sustainability would help remediation stakeholders apply sustainable remediation principles.

The consolidation and validation of tools and references and the compilation of data used to evaluate sustainability would help remediation stakeholders apply sustainable remediation principles. Training should help ease the concern that information might be misused, potentially overcoming another barrier.

4.2.3 Validation

Validating the methods or criteria used to evaluate or measure the sustainability of a site remedy is essential to the acceptance of the remediation practice. Validated results lend confidence in the specific methods used and in data reliability. However, no known process or system is currently available to validate the methods or criteria used in sustainable remediation. In fact, for some sustainability metrics, thresholds have not even been established to determine if criteria have been met. For instance, no minimum amount or percentage of recyclable material is required for remedial system construction or operation in order to meet sustainability criteria. The absence of certain quantitative criteria could further complicate the validation effort.

Validating the methods and metrics of deployed sustainable remedies is required to ensure uniform and impartial interpretation of whether sustainable goals are being met and to allow comparison between remedies. Validation is a key factor in achieving the acceptance of sustainable remediation practices. Without validation and/or certification, remediation stakeholders could resist accepting sustainability results.

To overcome this barrier, a system should be developed to provide validation and/or certification of the methods, processes, and/or criteria used in the practice of sustainable remediation. The system should include descriptions of the validation procedures and follow applicable industry standards such as ISO and ASTM International. With validated or certified results, the governing authorities and the public resistances to a proposed remedy would be based solely on the outcome of the sustainability evaluation.

4.2.4 Source Treatment and Removal Paradigm

Sustainable remedies are the most compelling for sites that may be difficult or impossible to clean up to generic criteria within a reasonable time frame, such as sites that have chlorinated solvent DNAPLs in groundwater. Some believe that rapid cleanup of these types of sources can be achieved through aggressive remediation. However, as

 Remediation DOI: 10.1002.rem

documented by the NRC (2005), ITRC (2007), and US EPA (2003), aggressive cleanup approaches often do not significantly change the time to achieve safe drinking water limits, nor significantly reduce the concentrations in the plume within "reasonable" time frames. Furthermore, there is no credible evidence that removing 50 percent or even 90 percent of the contaminants in source areas reduces cleanup times or dissolved-phase concentrations by the same percentages. Basic principles suggest that, where complete restoration is the goal, virtually every drop of the contamination must be treated or removed. Given the extended time that it takes to clean up heavily contaminated DNAPL sites, the remedies that use sustainability principles are, by their nature, sustainable over the time frames needed to achieve cleanup targets.

Remediation stakeholders have learned two lessons from trying to clean up DNAPL sites over several decades. The first lesson is that no regulation, policy, or regulatory culture can overcome the laws of physics and chemistry. The second is that some source remedies, even though they may not be considered sustainable, must be performed to protect human health and the environment.

The ongoing debate about source treatment will continue until highly effective and affordable technologies are available, which is only possible at some sites with additional research. In the meantime, that same approach should be brought to bear on ways to include sustainability impacts in the ongoing debate about source treatment.

4.2.5 The Risk-Assessment Dilemma

Historically, risk assessment was viewed as a method for focusing remedial efforts on the risks of highest concern. Unfortunately, the complications and complexities of implementing risk assessments have spawned another major segment of the remediation industry that sometimes provides little increase in clarity or focus. In short, the opportunity for disagreement exists at every step of the potentially long and expensive risk-assessment process and the high number of safety factor adjustments that have been built into the process.

The real risks of injury and death to persons participating in the remediation industry are far, far greater than the potential risks—which are overestimated as a matter of policy—to hypothetical humans who might come in contact with the contamination.

After a long process, the risk-assessment outcome is a conservative estimate of a projected possible risk level for a human receptor. In some cases, the human receptor is a "hypothetical receptor" for the purpose of having an endpoint for conducting the assessment. For carcinogens, this risk is often expressed as a potential increase in the incidence of cancer of one case among one million persons exposed for their lifetimes. This represents a very low level of risk, especially in the case of a "hypothetical receptor." In contrast, the "life years lost" of remediation workers due to fatalities during typical remediation activities versus theoretical cancer deaths of residents near a hazardous waste site can be calculated (Cohen et al., 1997). In this study, the authors concluded that "public health costs to remedial workers, in some cases, exceed the public health benefits" (p. 425). Accident occurrences around heavy equipment and fatalities from driving are two relatively well-known probabilities.

Therefore, the following dilemma surrounds the remediation industry: the real risks of injury and death to persons participating in the remediation industry are far, far greater than the potential risks—which are overestimated as a matter of policy (ITRC, 2008)—to hypothetical humans who might come in contact with the contamination. SURF struggles with this dilemma and suggests that the readers of this document consider our concern over this matter. After all, on top of the negative environmental consequences of high-energy consuming activities associated with traditional remediation projects, a real risk of illness, accident, injury, or fatality exists to workers in the remediation industry.

4.3 Economic

Sustainable remediation is likely to encounter resistance from business managers because it may initially be seen as potentially more costly than conventional approaches. Moreover, sustainable remediation may be resisted because it is an approach that is likely to be unfamiliar to many managers. These prejudices can be overcome only by a thorough analysis of the cost and other implications of sustainable remediation.

Government should help to promote sustainable remediation by encouraging sustainable approaches in its regulations and guidance documents and by providing direct economic incentives in the form of grants, low-interest loans, and tax relief.

Such an analysis must begin with an identification of the incremental costs of sustainable remediation. Then, those costs must be compared with the potential cost savings and other benefits likely to result from a sustainable approach. Although short-term costs may be higher, and because sustainable remediation is likely to emphasize innovative technologies, potential long-term cost savings must be balanced against increased short-term costs. In fact, sustainable remediation is likely to result in long-term savings because the remedies are more likely to yield long-term benefits. Furthermore, the remedies themselves may be less expensive than conventional approaches.

Apart from long-term cost savings, sustainable remediation also is likely to enhance the public image of the business and, therefore, avoid future enforcement initiatives. Thus, sound environmental stewardship is promoted, a topic that is likely to be embraced by the public for years to come. These positives must be weighed against the potential detriments of sustainable remediation: the possibility of increased short-term costs; the resistance of regulators to new, unproven approaches that may be seen as an attempt by business to avoid thorough cleanups; and the increased risk of remedy failure because of the use of innovative technologies.

In the end, business managers will only accept sustainable remediation if a convincing business case can be made demonstrating that benefits outweigh detriments. The business case can be made by comparing the potential benefits with the potential detriments and by encouraging the regulators to provide economic incentives that make sustainable remediation an attractive approach. Thus, any business case will presumably have to demonstrate that any incremental short-term costs will be outweighed by long-term cost savings and that the potential noneconomic benefits will outweigh the potential noneconomic detriments. Furthermore, because sustainable remediation techniques are likely to be required in the near-term future, the business case should cite the likely avoidance of future enforcement initiatives as a basis for introducing sustainable principles into current remediation projects. The fact that sustainable remediation is sound environmental policy also is likely to resonate with senior managers concerned with the public image of the business. Sustainable remediation will be more likely to be adopted by senior management if the company has already developed a sustainable policy.

Government should help to promote sustainable remediation by encouraging sustainable approaches in its regulations and guidance documents and by providing direct economic incentives in the form of grants, low-interest loans, and tax relief. Government should also encourage the development of market forces that will stimulate sustainable remediation, such as credit banking systems now in place in many jurisdictions for carbon credit trading. Government funding can be useful in supporting the research and development of sustainable approaches.

Remediation DOI: 10.1002.rem

The selection of sustainable approaches to remediation should also be encouraged through the tax code, an accepted approach to influencing business conduct. Remediation expenses, especially those incurred in connection with business property, could be considered capital expenses. Relief in the form of vehicles that permit businesses to continue to expense sustainable remediation costs or that provide for credits against tax liability for sustainable remediation would drive the remedy-selection process in the direction of sustainability. The political will to implement solutions such as these appears to be present and growing in significance; therefore, government intervention encouraging sustainable remediation could be a significant factor in the future.

The marketplace should also offer significant incentives encouraging sustainable remediation. In the past few years, carbon emissions have been reduced through the effective use of market forces, such as emissions banks. Similar market mechanisms should be designed to encourage sustainable remediation. Such mechanisms are already in place or under consideration in many related areas, such as natural resource damage credit banking. Business should expect the marketplace and the entrepreneurs operating in the marketplace to conceive of and develop mechanisms that provide private incentives for sustainable remediation in response to legislation (for example, the use of carbon credits). This innovative process should be encouraged.

In summary, businesses evaluating remedial options should develop and carefully consider the business case for sustainable remediation. Regulators should clearly signal their approval and encourage sustainable remediation in regulations and guidance, and the government should provide economic incentives. The marketplace should be encouraged to develop consistent methods and tools to make sustainable remediation approaches economically preferable.

Business should expect the marketplace and the entrepreneurs operating in the marketplace to conceive of and develop mechanisms that provide private incentives for sustainable remediation in response to legislation (for example, the use of carbon credits).

4.4 Regulatory and Legal

Most remediation (whether conducted voluntarily or pursuant to an agency order or agreement) is performed to meet legal requirements, protect human health and the environment, and minimize the risk of legal liability. In cases with regulatory agency involvement, the agency's regulations and guidance documents establish the standards and criteria for each step in the remedial process. Current remedy-selection regulations do not explicitly require consideration of sustainability in the remedial process, but neither do they prohibit it. As a result, sustainability has not received widespread consideration in the remedial process and, in some instances, has encountered skepticism from regulators who are unfamiliar with the concept and unsure how to incorporate it into the established remediation process.

Sustainability in the environmental context is a relatively new concept, first gaining widespread recognition in the context of sustainable development in the 1987 report of the World Commission on Environment and Development (Brundtland Commission, 1987). Since then, the term has gained popularity and is used in a variety of environmental contexts, including most recently in the context of sustainable remediation. The various applications of the term *sustainable* have resulted in numerous and inconsistent definitions, which has led to confusion. Absent a uniform and objective definition of *sustainable remediation*, lawmakers and regulators are likely to resist incorporating such a nebulous concept into legal authority. Before sustainable remediation is accepted by regulators and incorporated into the remedial process, lawmakers and regulators will need to understand what sustainable remediation encompasses, as well as its costs and benefits as presented in previous sections of this document.

Assuming that the definitional issue is resolved, the next step to forming a general sustainable remediation framework is to set criteria and metrics to evaluate the proposed sustainable remediation techniques. A reputable national organization should address this need by applying its scientific knowledge to sustainable remediation to develop appropriate criteria and metrics. With such standards, lawmakers will be able to incorporate the principles into statutes, and regulators will be able to promulgate meaningful rules and guidance to interject sustainability into the remediation process.

The significant barriers hindering the implementation of sustainable remediation are as follows: (1) lack of a well-defined framework and agreed-upon metrics, (2) lack of regulatory consensus of how to integrate these metrics and framework within the current regulatory structure, and (3) lack of financial or certification incentives to encourage innovation and adaptation of sustainable remediation practices.

The process of incorporating sustainable remediation into existing legislation and regulations can occur formally or informally. Currently, no formal steps exist to integrate sustainable remediation into legislation or to create any formal guidance documents. However, some agencies and remedial project managers are beginning to consider sustainability as an evaluation criterion in remediation selection on a case-by-case basis. Unfortunately, until a formal system is in place to provide guidance to these regulators, such an ad-hoc process will likely result in inconsistent application and oversight.

At least two approaches exist to formally integrate sustainability into site remediation: (1) enacting legislation and/or promulgating regulations and (2) establishing regulatory guidance that includes sustainability as a factor in decision making. Enacting legislation and/or promulgating regulations at the federal and state levels would force the consideration of sustainable remediation in environmental decision making, particularly during remedial alternative evaluation and selection. The potential benefit of this approach is that it requires sustainable remediation to be a factor in the decision-making process and ensures greater consistency of application. However, the problem with any such formalized procedure is the substantial time requirement entailed in the political and regulatory arenas and the significant efforts and cooperation needed by both Congress and the US EPA to pass or amend existing legislation or to promulgate new regulations. Furthermore, the political climate at the time of interest is a factor in the potential success of the implementation in any formal integration process. The second approach, establishing regulatory guidance that includes sustainability as a factor in decision making, would be more efficient than creating separate legislation but would have greater potential for varying application results.

Informal approaches also exist to integrate sustainability into the remediation process, but these approaches occur on a much smaller scale as agencies and remedial project managers take the initiative and apply sustainability principles to the projects under their purview. The primary concern of informal integration approaches is the inconsistency in implementation between different states and agencies and among different remedial project managers.

4.5 Summary of Impediments and Barriers

The significant barriers hindering the implementation of sustainable remediation are as follows: (1) lack of a well-defined framework and agreed-upon metrics, (2) lack of regulatory consensus of how to integrate these metrics and framework within the current regulatory structure, and (3) lack of financial or certification incentives to encourage innovation and adaptation of sustainable remediation practices. Despite these barriers, awareness of sustainability is established and increasing in our society, organizations are

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adapting and incorporating sustainable practices, and the public is expecting government and industry to provide sustainable goods and services. Section 6.0 documents assessments that use sustainable metrics, demonstrating the increasing interest and value for remedy selection and optimization. These practices lead to the implementation of more sustainable remedies. However, many remedies are not efficient or sustainable, because sustainable concepts were not considered or integrated in the selection or ongoing remedy evaluation. The combination of society's awareness and demand for sustainable practices will drive all organizations to implement sustainable practices when possible. Increased awareness of these concepts and societal demand will help overcome the barriers discussed.

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 Remediation DOI: 10.1002.rem

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5.0 A VISION FOR SUSTAINABILITY

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SURF's vision is for the remediation industry to contribute to planetary sustainability by promoting approaches and practices that take into consideration the long-term effects of remedial actions on the environment, stakeholder communities, and economics. This section outlines a practical approach of how to achieve this vision. Implementing this approach will result in a foundation for more consistent planning and implementation of stakeholder-supported sustainable remediation projects.

To achieve the vision for sustainable remediation, the following nine objectives must be achieved:

- Recognize diverse and emerging drivers for implementing sustainable remediation.
- Develop technical resources.
- Agree on regulatory aspects of sustainable remediation.
- Use valuation properly.
- Respond to market and government forces.
- Prepare for carbon trading and emissions credits.
- Adapt to sites of different scale.
- Develop a sustainable remediation framework.
- Implement strategies to attain the vision.

This section describes these objectives and proposes recommendations on how to achieve them.

5.1 Recognition of Diverse and Emerging Drivers

Much of the effort in sustainable remediation to date has been focused on reducing greenhouse gas emissions. This focus is largely the result of recent concerns about climate change being attributed to the significant amount of anthropogenic greenhouse gases that are generated in the world. While focusing on greenhouse gas emissions reduction is necessary and appropriate, it does not directly address other societal and economic issues or adequately consider other important environmental media (e.g., groundwater, subsurface soil, surface water).

Many businesses have adopted the "triple bottom line" (Elkington, 1994), which incorporates environmental and social values in addition to economic values in developing a company's balance sheet (see Exhibit 5-1) to facilitate broader thinking and accountability around sustainability. Consideration of the triple bottom line promotes broader thinking about the potential drivers to consider in remediation planning.

Traditional drivers for remediation activities include regulatory requirements, property transfers, and protection of human health and the environment. These traditional drivers were developed before sustainability was recognized as a critical component of remediation planning. Therefore, it is appropriate to identify new drivers to better frame sustainable remediation project objectives.

By focusing on sustainability drivers and being flexible to new drivers in the future, remediation activities will better address the full range of opportunities to incorporate sustainability principles and practices into remediation projects. The list that follows

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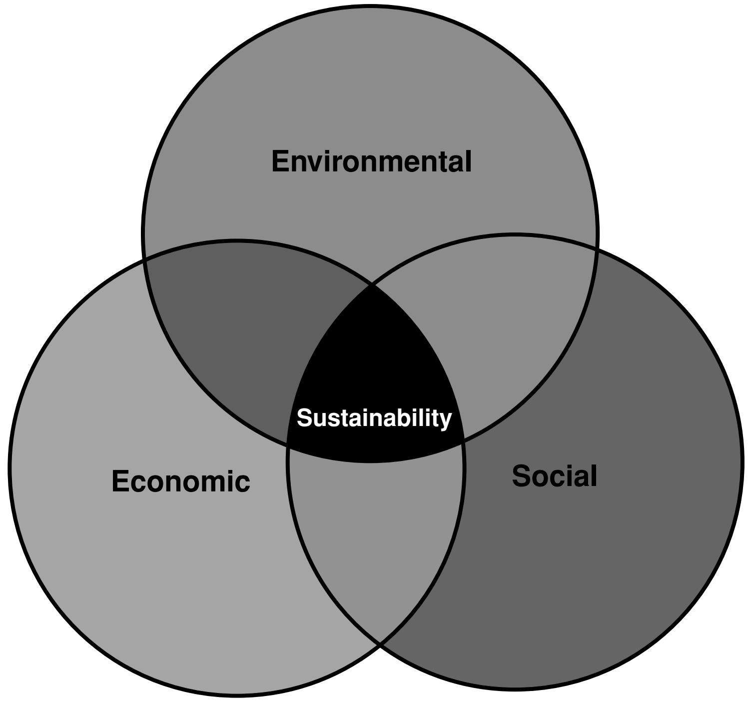

Exhibit 5-1. Triple bottom line

presents current and emerging drivers for sustainability, organized around the components of the triple bottom line:

- Social
  - Industry desire to improve corporate image and enhance social responsibility to improve shareholder value, reduce risk, and improve communities.
  - Nongovernmental organization advocacy pressure.
  - Public awareness of sustainability issues and requests to implement more sustainable practices.
- Environment
  - Pending climate-change legislation at the state or federal level (e.g., California, European Union, Western Climate Initiative, Regional Greenhouse Gas Initiative).
  - Federal Executive Order 13423, which requires federal agencies to implement sustainable practices.
  - Regulations and laws in other countries where remediation is mandated.
  - Net environmental benefit focus.
- Economic
  - Brownfield development incentives (including tax incentives) and real estate values.
  - Long-term environmental liability management and minimization.
  - Increased financial and liability transparency required by the Financial Accounting Standards Board and Securities and Exchange Commission in the United States, as well as the International Accounting Standards Board.

Remediation DOI: 10.1002.rem

It is important to note that these drivers are interrelated. For example, integration of sustainability into business operations could improve a company's corporate and social image and, thus, indirectly enhance economic value.

Sustainability, as a whole, is gaining prominence and is an important environmental, social, and economic consideration and will bring a whole new set of drivers to the remediation industry. The industry needs to be flexible in responding to these drivers as they become apparent.

5.2 Development of Technical Resources

Enhanced technical resources will be required to address the challenges associated with planning and implementing sustainable remedial actions. The subsections below highlight the technical resources that will need to be developed to achieve the sustainable remediation vision.

5.2.1 Sustainability Framework

The remediation industry needs a consistent framework that is accepted by all stakeholders and that is used to assess, implement, and monitor the sustainability elements of remediation projects. A commonly accepted framework will ensure objective assessments and appropriate focus on the benefits and detriments of the remedial alternatives being considered and also allow for an equivalent comparison of similar remediation approaches being implemented in different regions (including internationally; see Section 5.8 for a proposed framework).

5.2.2 Technical and Regulatory Guidance Documents

Technical and regulatory guidance documents are required to explain and educate stakeholders about the various aspects and processes of sustainable remediation. These documents should be posted on a central Web site and would become the "go-to" sources of information for individuals wanting to integrate sustainable principles into remediation programs. Guidance documents should be endorsed by all stakeholders involved in evaluating and implementing remediation activities (through a review process) and be kept updated, as appropriate. Regulatory agencies, government organizations, and industry groups would be the catalyst for developing such documents. These documents will take on greater credibility when a broad spectrum of remediation stakeholders review and comment on the documents. The following high-priority technical and guidance documents are needed:

Technical and regulatory guidance documents are required to explain and educate stakeholders about the various aspects and processes of sustainable remediation.

- Definitions and Terms
  Accepted existing definitions should be compiled from a number of different sources and should be available as an online reference. Definitions and terms, to the extent practicable, should complement existing sustainability terminology used by the sustainability industry. These definitions and terms can be developed as part of the technical and regulatory guidance document discussed above.

- Metrics
  The remediation industry should develop and agree upon a common set of metrics that can be used to assess and monitor the effectiveness of remedies at achieving sustainability goals. These metrics should include both leading and lagging indicators. Commonly used values for metrics (e.g., groundwater resource preservation, economic values for natural resources, carbon credits) should also be compiled and updated at an appropriate frequency. It is imperative that remediation metrics have broad acceptance by remediation stakeholders. Metrics are further discussed in Sections 5.3.1 and 5.8.

The remediation industry needs a common and accepted set of sustainable remediation tools to assess the potential impacts of remediation activities and to apply to the planning and operation phase of a project.

- Tools
  The remediation industry needs a common and accepted set of sustainable remediation tools to assess the potential impacts of remediation activities and to apply to the planning and operation phase of a project. These tools need sufficient flexibility to address the full range of sustainability drivers and metrics applicable to the project (e.g., carbon emissions, water and energy usage, energy footprint, waste generation/minimization, resource use or loss, and community support for long-term beneficial property use). Any software tool that is developed should be simple and user-friendly so that it can be used by a large number of technical professionals in the remediation industry.
- Regulatory Integration
  A guidance document that addresses how sustainable remediation can be integrated into the regulatory process is needed. This document could serve to educate both regulators and remedial project developers on how sustainability can be factored into existing regulatory evaluation criteria (e.g., the nine CERCLA evaluation criteria in the United States). Having a regulatory agency (e.g., the US EPA) take the lead for this integration would accelerate the effort.

5.2.3 Sustainability Certification Program

A sustainable certification program needs to be developed as a means to encourage sustainable remediation. The certification would reflect that sustainable practices and materials were integrated into a remediation project. For a certification program to be successful, there would need to be encouragement in the form of incentives to those responsible for cleanups. Some of this incentive will come from the drivers listed in Section 5.1. Other incentives could include accelerated regulatory review, opportunity to implement innovative sustainable technologies, tax deductions, and awards to projects and individuals for innovative and creative sustainability implementation. The certification programs could be stewarded by independent organizations that represent a cross-section of industry stakeholders.

5.2.4 Pilot Studies and Research

Pilot studies and research of the various aspects of sustainable remediation are necessary and could be highly beneficial. Pilot-study programs should be conducted to assess, quantify, or develop sustainable remediation strategies. Grants should be provided to researchers to conduct pilot studies and case studies, or research sustainable practices.

 Remediation DOI: 10.1002.rem

Grants could be funded through organization membership and subscriber fees, or by collaborating organizations (e.g., the US EPA, industry associations). In addition, stakeholders should partner with vendors to identify technology gaps and promote the development of new technologies aligned with the sustainable remediation vision.

5.2.5 Lessons Learned and Case Studies

A compendium should be developed of remediation projects where sustainability has been implemented, benefits it has provided, challenges in implementation, level of acceptance, and other lessons learned. An initial effort at this compilation is presented in Section 6.1. Rules of thumb should be developed to determine how renewable energy sources can be practically implemented at remediation sites.

Some steps are being taken to compile sustainability lessons learned and case studies (as referenced above). Many such experiences are being shared at conferences and are becoming available in the literature. However, without a leadership role by a research-oriented organization, the remediation industry has traditionally not achieved the level of cooperation necessary for creating a peer-review quality compendium of the type and size envisioned herein.

5.2.6 Education

Education and training should be provided for remediation industry stakeholders, as defined in Section 2.1, to help them better understand sustainability and how to integrate it into a remediation project. Training can be performed by a variety of training organizations. In addition, outreach to institutions of higher learning should be conducted to help them integrate sustainability into environmental curriculums.

A compendium should be developed of remediation projects where sustainability has been implemented, benefits it has provided, challenges in implementation, level of acceptance, and other lessons learned.

5.2.7 Technical Stewardship

The stewardship of sustainable remediation practices should be maintained by a group of stakeholders to assure that the proper resources and focus are provided to support sustainability in the remediation industry. This group could be part of a larger organization (e.g., the American Society of Civil Engineers) or a group without any affiliations (e.g., SURF). This group should be independent of any institution, government entity, industry, or other stakeholder and be composed of objective third-party individuals selected by those organizations directly involved with remediation efforts.

5.3 Agreement on Regulatory Aspects of Sustainability

Regulatory aspects of sustainability, as used in various regions of the world, are discussed in Section 2.0. For sustainability to be properly implemented, those designing and implementing remediation projects need concurrence from regulators on two important questions:

- How can a consistent approach for sustainability metrics be balanced with site-specific flexibility?

- What changes in policy and/or guidance are necessary to incorporate sustainability considerations into site cleanups?

5.3.1 Sustainability Metrics

No standard metrics currently exist for evaluating the relative sustainability of remedial alternatives. Organizations such as the World Business Council for Sustainable Development have proposed that metrics should address the triple bottom line of environmental, social, and economic elements of a given project. Section 5.8 proposes a framework for sustainable remediation consisting of 46 different sustainable practices and goals. Many items on this list can be converted into project metrics for sustainable remediation decision making, as well as be used for monitoring existing operations for sustainability metrics. In addition to metrics, a process for implementing metrics into a project, as well as validating their use, is necessary.

Recognizing that it will take time for organizational policies to be developed and agreed upon, a project-level approach is needed in the short term to integrate sustainability into the regulatory process.

It is important that the regulatory agencies and those responsible for site cleanups are operating with the same understanding of sustainable metrics. It is also important to understand the role of the regulator in the decision-making process. Once metrics are defined, agreement on how they relate to each other (valuation) is imperative (see Section 5.4).

5.3.2 Policy and Guidance Development

Sustainability considerations are already being factored into site cleanup decisions without any substantive changes to cleanup regulations and their implementing guidance. However, in order for the concepts to be fully embraced by the regulated community, it would be helpful for the US EPA (and state agencies) to provide some policy direction on how to integrate sustainability into existing remedial decision frameworks. It may also be useful to engage third-party groups involved in standards development, such as ASTM International, to provide guidance on how to develop and measure sustainability metrics for analysis of alternatives. Recognizing that it will take time for organizational policies to be developed and agreed upon, a project-level approach is needed in the short term to integrate sustainability into the regulatory process.

At a project level, project stakeholders need to agree upon how sustainability principles and practices will be integrated into the remediation project. It is imperative that all project stakeholders agree on the approach at the beginning of the process when remedial alternatives are developed and considered. In some cases, it may be necessary to provide education and other resources so that all stakeholders have the same basic level of understanding and can agree as to the integration of sustainability into the decision-making process.

5.4 *Proper Use of Valuation*

Valuation, when considered in the overall context of sustainability, can be a lightning-rod topic that pits economists against environmentalists. Environmentalists argue that economists put a value on everything, and some things cannot be valued. They are also concerned that typical cost-benefit approaches are not equitable between wealthier and poorer society members as well as between current and future generations. Economists argue that it is appropriate for natural resources to be used for the common good, that everything can be valued, and that valuation can be a benchmark for making decisions (Dresner, 2002).

The challenges of bringing valuation principles and practices to the remediation industry are not insignificant. There has traditionally been great reluctance among environmentalists, community stakeholders, elected officials, and regulators to discuss, much less accept, if it is appropriate to:

- place a monetary value on any natural resource;
- place a monetary value on a groundwater resource and use its value in a decision-making process;
- assess contaminated property in terms of human-use loss for current generations or future generations;
- compare the incremental lifetime cancer risk of a human receptor against the potential of an accident or fatality associated with the person implementing a remedial action;
- implement a long-term land-use control that prevents resource access to future generations; and
- for natural resource damages, scale remediation projects based on the dollar value of the damage or resource equivalency.

The solution to the valuation challenge can be addressed in terms of respecting and understanding all views and realizing that solutions lie in understanding the interconnectedness of problems (Hawken et al., 1999).

The solution to the valuation challenge can be addressed in terms of respecting and understanding all views and realizing that solutions lie in understanding the interconnectedness of problems.

Section 5.2.2 addresses the need for the industry to adopt commonly accepted sustainability metrics. Until this is completed, SURF recommends that project stakeholders have transparent communication about how valuation will be used in project decisions.

There is certainly a role for valuation in all project decisions. However, its use has to be carefully considered and agreed upon by stakeholders to have any significant meaning. Transparent communications about how different project elements are valued will allow broader acceptance of valuation applications on a project.

One potential application for valuation could be the use of sustainable remediation units—a group of metrics that express the value of remediation in terms of sustainability value. Some considerations of a sustainable remediation unit could be:

- kilogram of contaminant removed per pound of greenhouse gas;
- kilogram of contaminant removed per increase in ecological service;
- kilogram of contaminant removed per increase in human-use value;
- kilogram of contaminant removed per consumption of natural (e.g., soil disposed) or nonrenewable resource (e.g., fossil fuel); and
- kilogram of contaminant removed per increase in restored volume of groundwater, surface water, soil, or sediment.

SURF believes that representing contaminant removal in terms of impact to triple-bottom-line criteria helps to place the benefit of the remedial action in terms of sustainability improvements. Other considerations for valuation could include normalizing risk with sustainability benefit and regulatory goals. Here, the term *risk* would not only refer to human and ecological risks as determined through classical human health and ecological risk assessments, but also "risk" in terms of injury and fatality for on-site workers and individuals in the community.

5.5 Market and Government Forces Driving Sustainability

SURF recognizes that market forces can be constructive or destructive and can often create ambiguous or seemingly conflicting results.

This vision of sustainability recognizes that market and government forces can and must be used to develop innovative solutions to long-term environmental problems. Business models, which currently focus on cost and schedule, should be modified to promote environmentally beneficial, economically efficient, and socially responsible approaches to site cleanup. To understand the role that market forces play in achieving SURF's vision, the following working definition of what constitutes a sustainability market is useful (Presidio School of Management, 2008):

> Ideally, a market that is capable of operating continuously while meeting today's (global) economic, environmental, and social needs without compromising the opportunity for future generations to use the market to meet their own needs.

The vision is to promote approaches and practices that take into consideration the long-term effects of remediation technologies on the environment and stakeholders. SURF recognizes that market forces can be constructive or destructive and can often create ambiguous or seemingly conflicting results.

There is marketing value for the terms *green* or *sustainable*. However, these terms increasingly are misused for promotional purposes, a phenomenon commonly known as "green washing." In a recent Economist Intelligence Unit survey, 71 percent of executives agreed that "too many organizations use sustainability merely as a public relations tool" (Economist Intelligence Unit, 2008). The vision is based on practices that produce verifiable, measurable, and long-term benefits to the environment and communities. For sustainable remediation to be valued and adopted by stakeholders, SURF recommends that the remediation industry adopt the following characteristics of sustainability markets:

- *Make sustainability a long-term commitment*. Firms of all types are becoming "green," but long-term commitment means sustainability is actually promoted internally and externally.
- *Support or enhance ecological services that perform naturally or mimic natural processes.*
- *Maintain flexibility in how human needs are met while recognizing that changes are inevitable*. Examples of industries that are currently making broad shifts toward more sustainable practices in response to market forces include automakers, the energy sector, wood products/furniture, agriculture, aquaculture, and home building.
- *Include the value of natural resource services using metrics that reflect both ecological and human-use values.*
- *Respond to marketplace trends.*

Government and state organizations will also play a role in affecting market forces impacting sustainability by developing programs. Exhibit 5-2 highlights selected federal and state programs promoting sustainability; although this list is not comprehensive, it

Remediation DOI: 10.1002.rem

Exhibit 5-2. Federal/state programs promoting sustainability

California Assembly Bill 32	Requires that statewide carbon emissions be reduced to 1990 levels by 2020, with the goal of achieving a stable climate by 2050.
California Climate Action Registry	Voluntary greenhouse gas registry to protect and promote early actions to reduce greenhouse gas emissions; develops and promotes greenhouse gas reporting standards and tools to measure, monitor, third-party verify, and reduce greenhouse gas emissions.
California Self-Generation Incentive Program (SGIP)	Provides incentives for installation of renewable energy systems and rebates for systems sized up to 5 megawatts (MW). Qualifying technologies include photovoltaic systems, micro-turbines, fuel cells, and wind turbines (http://www.epa.gov/cleanenergy).
Clean Energy Initiative	Provides technical assistance and policy information, fosters creation of public/private networks, and formally recognizes leading organizations that adopt clean energy policies and practices.
Clean Energy-Environment State Partnership Program and Clean Energy-Environment Municipal Network	Supports development and deployment of emerging technologies that achieve cost savings through energy efficiency in residential and commercial buildings, municipal facilities, and transportation facilities (http://www.epa.gov/cleanenergy/energy-programs/state-and-local/index.html).
Cleanup-Clean Air Initiative	Program to reduce diesel emissions and greenhouse gases at Superfund and redevelopment sites.
U.S. Department of Energy's Energy Efficiency and Renewable Energy (EERE)	Offers grants or cooperative agreements to industry and outside agencies for renewable energy and energy-efficiency research and development. Assistance is available in the form of funding, property, or services (http://www1.eere.energy.gov/financing/types_assistance.html).
Environmentally Responsible Redevelopment and Reuse (ER3) Initiative	Uses enforcement incentives to encourage developers, property owners, and other parties to implement sustainable practices during redevelopment and reuse of contaminated sites (http://www.epa.gov/compliance/cleanup/redevelop/er3/).
Green Power Partnership	Helps organizations buy green power to expand the market of environmentally preferable renewable energy sources (http://www.epa.gov/greenpower).
ENERGY STAR (Joint US EPA/ U.S. Department of Energy)	Product ratings provide guidelines for energy management in buildings and plants and general designs for energy-efficient commercial buildings.
Minnesota Pollution Control Agency (MPCA) Green Practices for Business, Site Development, and Site Cleanups: A Toolkit	Provides online tools to help organizations and individuals make informed decisions regarding sustainable best management practices for use, development, and cleanup of sites (http://www.pca.state.mn.us/programs/p2-s/toolkit/index.html).
National Action Plan for Energy Efficiency	Engages public/private energy leaders (electric and gas utilities, state utility regulators and energy agencies, and large consumers) to document a set of business cases, best management practices, and recommendations designed to spur investment in energy efficiency (http://www.epa.gov/cleanenergy/energy-programs/napee/index.html).
New Mexico Mandatory Greenhouse Gas Reporting Regulations	Requires industry, including power plants, oil and gas refineries, and cement plants, to report greenhouse gas emissions. Requirement will be phased in, beginning for reporting year 2008.

(*Continued*)

Exhibit 5-2. Continued

The Climate Registry	Sets standards for the measurement, verification, and public reporting of greenhouse gas emissions throughout North America; supports both voluntary and mandatory reporting programs.
U.S. Conference of Mayors	Resolution to reduce the nation's greenhouse gas emissions to 7 percent below 1990 levels by 2012.
U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED)	Rating system for new or existing building construction.
U.S. HR 2635	2007 bill requiring the federal government to freeze carbon dioxide emissions by 2010 and be carbon-neutral by 2050.
U.S. Omnibus Spending Bill (2007)	Includes US EPA requirement to issue a rule by 2009 establishing an economywide greenhouse gas reporting program.
USDA's Conservation Reserve Program	Encourages farmers to convert environmentally sensitive acreage to resource-conserving vegetative cover, such as tame or native grasses, wildlife plantings, trees, filter strips, or riparian buffers, and provides cost-share assistance for up to 50 percent of participants' costs in establishing approved conservation practices (http://www.nrcs.usda.gov/programs/crp/). The Conservation Reserve Program is also discussed on a Web site maintained by Ducks Unlimited (http://www.ducks.org/Conservation/GovernmentAffairs/1617/ConservationReserveProgram.html).
Western Climate Initiative	Regional goal to reduce greenhouse gas emissions by 15% from 2005 levels by 2020.

does represent the range of programs being considered. Some of these programs will create an opportunity for sustainable remediation to be more accepted because it is in alignment with federal and state programs promoting sustainability.

5.6 Preparation for Carbon Trading and Emission Credits

Creative approaches are required in the design of remediation projects so that the remedial goals of protecting human health and the environment are achieved while adverse environmental impacts in other areas are minimized. Development and implementation of these approaches will require policy and regulatory changes to allow consideration of collateral environmental impacts in the remedy-selection process. While this topic could have been discussed in the previous section on market forces, it has the potential to create a market disruption and, as such, warrants its own section.

Beyond implementing remedies that provide the greatest net environmental benefit, opportunities may exist to further minimize environmental impacts through development or selection of renewable energy sources, implementation of emissions control technologies, future land-use designation, or other creative means. In some cases, these approaches can qualify for emissions credits that can be sold or traded, thereby mitigating the additional implementation costs.

Emissions trading is an administrative approach used to control greenhouse gas emissions by providing economic incentives for achieving reductions in these emissions.

Although this approach is currently voluntary in the United States, markets are developing and legislation is being discussed. Emission offsets can currently be purchased or sold through voluntary over-the-counter markets, through trading systems such as the Chicago Climate Exchange, or as renewable trading certificates (RECs). RECs are tradable environmental commodities representing one megawatt-hour of electricity generated from a renewable energy source. The "green" energy is then fed into the electrical grid, and the accompanying REC can then be sold in the open market.

The role of carbon trading and emission credits for the remediation industry is unclear at this time. The remediation industry is monitoring this issue, and market forces that focus on creating value for sustainable remediation will likely drive the industry's adaptation to the opportunities that these markets can create.

5.7 The Need for Scalability to Range of Sites

Sites warranting remediation vary greatly in terms of complexity, types of contaminants, media impacted, and risks to human health and the environment. There is a need for an approach to implement sustainable remediation that can be flexible to site variables, such as size, location, stakeholders, land use, and types of contaminants. Remedial goals can be highly variable and sometimes arbitrary as far as actual risk to public health or the environmental. Therefore, while remedial projects should follow a standard protocol that incorporates sustainability criteria, additional steps and processes may be needed depending on site-specific characteristics and location.

The applicability of flexible sustainable methodologies to differently sized sites could follow the tiered approach used with risk-based corrective action. A tiered approach starts with a generic sustainability-based screening level (Tier 1), followed by a site-specific evaluation, if applicable (Tiers 2 and 3). A Tier 1 analysis would assess basic sustainability metrics (e.g., carbon dioxide impacts, waste generated, impact to natural resources, costs) and be applicable to simple project sites (e.g., single-media treatment) or used for screening of complex sites. The "basic sustainability metrics" parameters would be those widely accepted in the industry as being the typical metrics used in an assessment. The Tier 1 analysis can incorporate elements of a life-cycle assessment but it would not be in-depth. The information for the analysis would be easily attainable through the remedial planning process and can be integrated into standard sustainability tools currently being developed by the remediation industry (see Section 3 for a survey of tools).

There is a need for an approach to implement sustainable remediation that can be flexible to site variables, such as size, location, stakeholders, land use, and types of contaminants.

A Tier 2 analysis would be applicable to more complex sites where more confidence is needed in the sustainability assessment results. Tier 2 would involve a more detailed and comprehensive analysis of the project that may integrate a detailed life-cycle inventory and life-cycle assessment of the project. This more detailed analysis could involve using simple spreadsheet tools and analytical procedures or involve an application of the ISO 14044 Methodology (ISO 14044:2006(E)), and use commonly available specialized software (e.g., SimaPro or GaBi).

A Tier 3 analysis could be applicable to project sites where valuation is utilized. The input parameters for valuation estimates should be detailed and well documented (i.e., coming from a Tier 2 analysis). Likewise, the application of valuation parameters should be well documented and defendable (e.g., groundwater resource values, human-use values of natural resources).

For the purposes of this article, "valuation" does not include the normalization or scoring of sustainability metrics using commonly used decision analysis procedures. Normalizing and scoring of sustainability criteria can be used for any of the three tiers described herein.

It should also be recognized that some projects might be of a size or nature that makes considering sustainability activities unnecessary.

5.8 Proposal for Sustainable Remediation Framework

SURF proposes a sustainable remediation framework that represents the confluence of environmental, social, and economic factors for decision making.

SURF proposes a sustainable remediation framework that represents the confluence of environmental, social, and economic factors for decision making. Framework, as defined herein, refers to a range of practices and objectives that can be integrated into a project to increase its sustainability features. A working group within SURF proposed 46 different sustainable practices and objectives. A key resource for this effort was the document *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* (US EPA, 2008b). These practices and objectives were grouped around the triple-bottom-line elements of environment, social, and economic and nine subelement categories (i.e., water resources, land and ecosystems, materials/waste minimization, long-term stewardship, atmospheric emissions, life-cycle costs, environmental justice, human health, and safety). Each of these 46 practices and objectives can be mapped to a triple-bottom-line element and category as presented in Exhibit 5-3. In reviewing this recommendation, it is clear that some practices and objectives can be categorized into more than one triple-bottom-line element and subelements. It is not practical to implement all 46 practices and objectives on every project. The intent of this framework is to provide a list of sustainable practices and objectives that may be considered.

This framework, if accepted by all remediation industry stakeholders, could represent a common basis by which all remediation projects are evaluated and implemented. For example, the framework could be used as:

- a basis to compare remediation alternatives in a feasibility study, using the framework as a checklist to verify a range of sustainability practices and objectives that were considered;
- a tool to identify areas where ongoing remediation projects can be improved;
- part of an evaluation during a review of remediation projects that have previously not been evaluated in terms of sustainability (e.g., during CERCLA five-year reviews, periodic optimization reviews); and
- a tool for use by prospective purchasers when considering buying properties with ongoing remediation activities to assess the sustainability of a remedial action.

The proposed framework can also be adapted to different types of decision analysis scoring techniques and can be modified to integrate appropriate resource valuation considerations.

5.9 Implementation Strategies to Achieve the Vision

To achieve the vision of implementing sustainable remediation, the remediation industry must make progress in the following three areas: technical resource integration,

Exhibit 5-3. Sustainable remediation framework

Sustainable Remediation Practices and Objectives	Triple-Bottom-Line Element: Environmental	Economic	Social	Subelements: Water Resources	Land and Ecosystems	Materials/Waste Minimization	Long-Term Stewardship	Atmospheric Emissions	Energy Efficiency	Life-Cycle Costs	Environmental Justice	Human Health and Safety
Minimize fresh water consumption	■			X								
Maximize water reuse	■			X		X						
Conserve groundwater resources	■			X			X					
Prevent runoff and negative impacts to surface water	■			X	X							X
Use native vegetation requiring little or no irrigation	■			X	X							
Minimize bioavailability of contaminants through source and plume control	■				X							
Maximize biodiversity	■				X		X					
Minimize soil and habitat disturbance	■				X		X					
Favor minimally invasive *in situ* technologies	■				X							
Favor low-energy technologies (e.g., bioremediation, phytoremediation) where possible and effective	■				X			X	X			
Protect native ecosystem and avoid introduction of non-native species	■				X		X					
Minimize risk to ecological receptors	■				X		X					
Preserve natural resources	■			X	X		X					
Use telemetry or remote data collection when possible	■					X			X			
Use passive sampling devices where feasible	■					X		X	X			
Use or generate renewable energy to the extent possible	■						X	X	X			
Reduce emissions of greenhouse gases contributing to climate change	■						X	X				
Reduce emissions of criteria pollutants	■							X				
Prevent offsite migration of contamination	■						X					
Integrate flexibility into long-term controls to allow for future efficiency and technology improvements	■	■					X			X		
Invest in carbon offsets	■	■								X		
Minimize material extraction and use	■	■				X				X		
Minimize waste	■	■				X				X		
Maximize materials reuse	■	■				X				X		
Recycle or reuse project waste streams		■				X				X		

(*Continued*)

Exhibit 5-3. Continued

Sustainable Remediation Practices and Objectives	Triple-Bottom-Line Element: Environmental	Economic	Social	Subelements: Water Resources	Land and Ecosystems	Materials/Waste Minimization	Long-Term Stewardship	Atmospheric Emissions	Energy Efficiency	Life-Cycle Costs	Environmental Justice	Human Health and Safety
Use operations data to continually optimize and improve the remedy		X							X	X		
Consider the net economic result		X								X		
Consider cost of the "sustainability delta," if any		X								X		
Improve the tax base/economic value of the property/local community		X	X		X		X			X	X	
Maximize employment and educational opportunities		X	X				X				X	
Minimize O&M cost and effort		X	X				X			X		X
Minimize health and safety risk during remedy implementation		X	X				X			X	X	X
Maximize acres of a site available for reuse		X	X				X				X	
Maximize number of sites available for reuse		X	X				X				X	
Use locally sourced materials	X	X	X			X						
Minimize noise, odor, and lighting disturbance	X		X				X				X	X
Favor technologies that permanently destroy contaminants	X		X		X		X					X
Avoid environmental and human health impacts in already disproportionately impacted communities			X		X		X				X	X
Consider net positive/negative impact of the remedy on local community			X				X				X	X
Assess current, potential, and perceived risks to human health, including contractors and public, over the remedy life cycle			X				X				X	X
Prevent cultural resource losses			X				X				X	
Integrate stakeholders into decision-making process			X				X				X	
Solicit community involvement to increase public acceptance and awareness of long-term activities and restrictions			X				X				X	
Maintain or improve public access to open space			X				X				X	
Create goodwill in the community through public outreach and open access to project information			X				X				X	
Consider future land uses during remedy selection and choose remedy appropriately			X				X			X	X	

Remediation DOI: 10.1002.rem

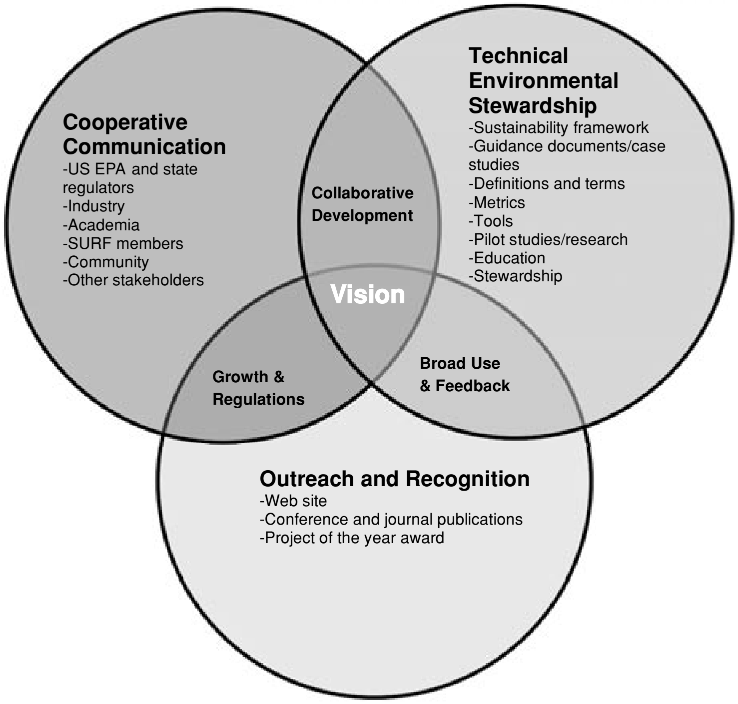

Exhibit 5-4. Components of opportunity to achieve vision

cooperative communication, and outreach and recognition. Activities within these three categories are related as shown in Exhibit 5-4.

5.9.1 Technical Resource Integration

The vision for sustainable remediation will be partly accomplished by including trained professionals and incorporating other resources on projects. Commonly accepted technical resources should be made widely available and readily accessible and should be consistently implemented. Short-term goals should focus on recommendations for technical development and acceptance of a sustainability framework, technical and regulatory guidance documents, pilot studies and research, lessons learned and case studies, education, and technical stewardship (see Section 5.2).

5.9.2 Cooperative Communication

By emphasizing cooperative communication, the environmental remediation community should encourage transparent and reciprocal communication among regulators, industry, academia, and other stakeholders. At the project level, communication can take the forms of local public meetings, publication and distribution of fact sheets, and dedicated attention to answering stakeholder questions and concerns. At the industry level, communication will be necessary to keep sustainable remediation stakeholders current on drivers, market and regulatory trends, and best practices. The organization leading technical stewardship (see Section 5.2) could also lead this communication effort.

5.9.3 Outreach and Recognition

Sustainable remediation activities will gain momentum, improve, and spread via outreach and recognition activities. Potential outreach activities should include publications (both peer-reviewed and non-peer-reviewed), participation in conferences, and maintenance of a Web site as a central repository of sustainable remediation activities. Examples of recognition should include establishing awards for creative and sustainable projects.

Outreach activities can be facilitated by: (1) educating key stakeholders about sustainable remediation activities and practices; (2) organizing conferences focusing on sustainable remediation; (3) hosting online workshops or Webinars; (4) creating a Web site focused on sustainable remediation with key presentations, articles, and online workshops; (5) increasing the number of sessions focusing on sustainable remediation at other remediation conferences; (6) continuing to present sustainable environmental remediation projects at conferences and feature these projects in publications; (7) preparing materials and work with interested universities to incorporate sustainable remediation into university curricula (over the long term); and (8) organizing workshops for interested parties. These activities are examples of the types of activities necessary for realizing the sustainable remediation vision.

5.10 Summary for a Vision for Sustainability

For sustainable remediation to be effectively and productively implemented, SURF recommends that remediation industry stakeholders view the role of sustainable remediation consistently and value it as important to remediation planning, implementation, operations, and decommissioning project life cycle. Widely accepted industry guidance, metrics, and tools that are applicable to a range of sites will promote consistency in the practice of sustainable remediation. To achieve the desired level of stakeholder acceptance, cooperative communication among all stakeholders is imperative.

Sustainable remediation is a component of sustainability, which has many dimensions. SURF believes it is important that the practice of sustainable remediation be responsive to issues and markets as they change and advance (e.g., be amenable to carbon trading and emission credits). When sustainable remediation is effectively and productively implemented, stakeholders will be promoting approaches and practices that take into consideration the long-term effects of remedial actions on the environment, society, and economics.

Paul Favara, P.E., has over 25 years of experience in the environmental field. He is a registered engineer in the State of Florida and leads the global sustainable remediation practice at CH2M HILL. He received his BS in business-oriented chemistry from Western Michigan University and an MS in environmental engineering from the Illinois Institute of Technology.

Bradley A. Barquest, R.G., is a member of United Technologies Corporation's Corporate Remediation Group. His focus is in the area of soil, sediment, and groundwater remediation. He received his BS in geology from the University of Wisconsin–Madison and his MS in hydrogeology from Baylor University.

Remediation DOI: 10.1002.rem

Louis P. Bull, PH.G, R.G., is director of groundwater protection with Waste Management. He is responsible for overseeing hydrogeologic-related activities at landfills owned or operated by Waste Management, including the implementation of the groundwater and leachate monitoring programs. He is also an active committee member of several national associations, including ASTM, Environmental Research and Education Foundation, and the Interstate Technology and Regulatory Council.

Angela Fisher is a lead environmental engineer in the Environmental Technology Laboratory at General Electric's Global Research Center in Niskayuna, New York. Her current research interests include the development of sustainable remediation practices. She received her MS in environmental engineering from The Pennsylvania State University, where her research focused on microbial dissimilatory iron reduction with the long-term goal of using it for the immobilization of heavy metals and radionuclides.

Elisabeth L. Hawley, P.E., is an environmental engineer in Malcolm Pirnie's Northern California office, where she works on environmental restoration projects involving site characterization and remedial strategies to achieve site closure. She has a BS in environmental engineering science and an MS in civil and environmental engineering from the University of California, Berkeley.

Karin S. Holland, REA, LEED AP, is a staff scientist with Haley & Aldrich Inc. Her experience encompasses environmental management systems, greenhouse gas inventories, sustainability appraisals, compliance auditing, training, permitting, and investigating across the United States and abroad. She has completed an MA in natural sciences from the University of Cambridge (U.K.) and an MS in law and environmental science from the University of Nottingham (U.K.).

Maryline C. Laugier, P.E., LEED AP, is a senior project engineer at Malcolm Pirnie Inc. Her focus is in the areas of hazardous waste remediation and adaptation to climate change for water utilities. She received her BS in geological engineering from École Nationale Supérieure de Géologie and her MS in civil and environmental engineering from the University of California, Berkeley.

Gary J. Maier, P.E., has over 28 years of experience providing engineering and environmental services to the industrial marketplace. He currently serves as a senior program manager within the oil and gas–sector practice of AECOM Environment. He earned his degree in chemical engineering from Michigan State University.

Michael E. Miller, PhD, is a senior environmental chemist at CDM in Cambridge, Massachusetts, where he leads the firm's Remedial Technologies initiative. He specializes in bioremediation as well as other *in situ* technologies for remediation of contaminated soil and groundwater; the evaluation of the fate and transport of organic and inorganic contaminants in soil, water, and air; and environmental statistics. Dr. Miller received his BA in chemistry from Swarthmore College and his MS and PhD in physical and inorganic chemistry from Cornell University.

Ralph L. Nichols is a Fellow Engineer at the U.S. Department of Energy Savannah River National Laboratory in Aiken, South Carolina. His focus is on testing new methods for the characterization and remediation of soil and groundwater contaminated with metals and radionuclides. He received his BS in geological engineering from the University of Missouri–Rolla and his MS in environmental engineering from the University of Oklahoma.

John R. Ryan is a vice president with AECOM. He has 28 years of experience in the environmental field, completing a broad range of site cleanup, brownfield acquisition, and sustainable development projects for public and private clients. He served as a liaison delegate to the World Business Council for Sustainable Development and its U.S. affiliate, the U.S. Business Council for Sustainable Development. He received an MPS in agricultural and environmental engineering from Cornell University.

L. Maile Smith, P.G., is a senior geologist with Northgate Environmental Management Inc. in Oakland, California. She is Northgate's corporate sustainability coordinator, in which role she develops, administers, and advises on sustainability programs and applications. Her technical focus area is the characterization, remediation, optimization, and long-term management of chlorinated hydrocarbon sites. She received a BS in geology from San Jose State University and an MS in geology from the University of British Columbia.

Daniel J. Watts, PhD, recently retired as Panasonic Professor of Sustainability at the New Jersey Institute of Technology in Newark, New Jersey. He currently is serving as a research professor at the Institute. His research interests include application of sustainability principles to industrial activities and emerging contaminants in water. Dr. Watts received his BSc in chemistry and botany from The Ohio State University and his AM and PhD in botany and organic chemistry, respectively.

Remediation DOI: 10.1002.rem

6.0 APPLICATION OF SUSTAINABLE PRINCIPLES, PRACTICES, AND METRICS TO REMEDIATION PROJECTS

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The review and discussion of the application of sustainable principles, practices, and metrics to remediation projects has been part of SURF's mission since its inception. In response to the growing body of information suggesting that global climate change is correlated with the use of fossil fuels and the attendant release of carbon dioxide into the atmosphere, assessments that consider carbon emissions and consumed resources (e.g., energy, fuel) have become part of wider evaluations at all stages of remedial action, from investigation to optimization. Remediation industry stakeholders have already begun evaluating the environmental, economic, and social impacts (i.e., the triple bottom line) of proposed and ongoing remediation projects to inform their remedial decisions.

Reducing the inherent consumption of energy, raw materials, and other consumables is the most significant opportunity for implementing more sustainable remedial actions. The traditional remedial technology evaluation process does not assess greenhouse gas emissions, natural resource consumption, energy use, worker safety, and/or local and regional impacts. Assessments that include sustainability are additive to conventional remedy-selection processes that have addressed cost, risk reduction, and compliance with existing laws, among other selection criteria. By including a wider suite of metrics in remedial program decisions, more holistic and sustainable decisions are made.

This section is a case study summarizing the work of stakeholders at actual sites who have begun considering sustainability and sustainable metrics, such as greenhouse gas emissions, in their decision making.

6.1 Sustainability at Actual Sites

This section presents representative examples of assessments where sustainability metrics were an explicit element in the overall assessment have been compiled. These assessments both illustrate the discussions presented in previous sections and provide examples of the broad range of applications where sustainability has been a factor in decision making. Summary tables are presented as a reference for the reader's further exploration of the utility of assessments that include sustainability. Attributes of the case studies that are included in the tables are as follows:

- site name, location, US EPA region (where appropriate), primary driver, and site status;
- impacted media, contaminants, and technologies evaluated; and
- regulatory framework, stage of the project (i.e., regulatory program), and various attributes of the assessment.

Exhibit 6-1 summarizes representative assessments from the United States, Exhibit 6-2 shows the geographical distribution of assessments summarized in Exhibit 6-1, and Exhibit 6-3 summarizes some of the assessments conducted by the international community.

Assessments have been conducted at many sites by various regulatory entities, industry service providers, and site owners. The level and extent of incorporation of sustainability vary. The primary drivers triggering the assessments were redevelopment,

Exhibit 6-1. Summary of U.S. sustainability assessment examples

Site	Regulatory Framework, EPA Region, Location (State)	Purpose	Impacted Media, Contaminant(s)	Technologies Evaluated	Primary Driver and Status	Theme: Minimize/Eliminate Energy or Natural Resource Consumption	Theme: Harness/Mimic a Natural Process	Theme: Reduce/ Eliminate Releases to Environment, Especially Air	Theme: Reuse/Recycle Inactive Land or Discarded Materials	Theme: Use of Technologies that Permanently Destroy Contaminants	Triple Bottom Line: Environmental	Triple Bottom Line: Economic	Triple Bottom Line: Social	Reference or Source	Contact
Altus Air Force Base	CERCLA 6 (OK)	Supported explanation of significant differences. Chose solar power used to recirculate contaminated groundwater in low-energy *in situ* bioreactor.	Landfill Leachate Chlorinated solvents	Soil vapor extraction and pump and treat	Optimization Implemented	X	X	X		X	X	X	X	EPA Technology News and Trends, Issue 30, May 2007	Erica.Becvar@brooks.af.mil
Altus Air Force Base	CERCLA 6 (OK)	Investigate passive treatment system as replacement for pump and treat	Groundwater Chlorinated solvents	Biowall	Optimization Implemented	X	X	X	X	X	X	X		Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil
Baird and McGuire	CERCLA 1 (MA)	Minimize carbon dioxide equivalent emissions from long-term operation and maintenance of pump-and-treat system.	Groundwater SVOCs	Combined heat and power engine or turbine with heat transfer	Optimization Proposed	X		X			X	X		Dorothy Allen, Massachusetts Dept. of Environmental Protection	Dorothy.T.Allen@state.ma.us
Bell Landfill	CERCLA 3 (PA)	Supported explanation of significant differences	Landfill Leachate Dissolved iron	Off-site disposal, constructed wetlands, spray irrigation	Optimization Implemented	X		X			X	X	X	David E. Ellis, DuPont	David.E.Ellis@usa.dupont.com
Brevard	Closed Landfill 4 (NC)	Supported viability of recycling landfilled waste polyethylene terephthalate (PET)	N/A N/A	Production of virgin plastic vs. recycling landfilled waste	Recycle Studied	X		X	X		X	X	X	David E. Ellis, DuPont	David.E.Ellis@usa.dupont.com

(continued)

Exhibit 6-1. Continued

Site	Regulatory Framework, EPA Region, Location (State)	Purpose	Impacted Media, Contaminant(s)	Technologies Evaluated	Primary Driver and Status	Theme: Minimize/Eliminate Energy or Natural Resource Consumption	Theme: Harness/Mimic a Natural Process	Theme: Reduce/ Eliminate Releases to Environment, Especially Air	Theme: Reuse/Recycle Inactive Land or Discarded Materials	Theme: Use of Technologies that Permanently Destroy Contaminants	Triple Bottom Line: Environmental	Triple Bottom Line: Economic	Triple Bottom Line: Social	Reference or Source	Contact
Burlington Mine Site	State VCP 8 (CO)	Reclaimed mine site	Soils and Surface Water Acid mine drainage, metals	Passive stream diversion, containment of waste rock, and mitigation of avian impacts	Remediation Implemented	X	X	X	X		X	X	X	EPA Technology News and Trends, Issue 37, July 2008	jcowart@walshenv.com
Carswell Joint Reserve Base	CERCLA 6 (TX)	Investigate passive, bio-based technology	Groundwater Chlorinated solvents	Biowall	Optimization, Implemented		X	X	X	X	X	X		Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil
Carteret	State 2 (NJ)	Supported remedy selection	Soil Arsenic and lead	Excavation and off-site disposal, *ex situ* stabilization, capping	Re-development Proposed	X		X	X		X	X	X	David E. Ellis, DuPont	David.E.Ellis@usa.dupont.com
Chambers Works - Salem Canal	RCRA, State 2 (NJ)	Supported remedy selection	Groundwater Impacting Surface Water SVOCs	Extraction well, groundwater collection trench, sheet pile barrier with and without pumping wells, sand cap, geocomposite layer thin cap, aquablock cap, hydraulic dredging, clamshell dredging, *in situ* stabilization	Remediation Approved	X		X			X	X	X	David E. Ellis, DuPont	David.E.Ellis@usa.dupont.com

(continued)

Exhibit 6-1. Continued

Site	Regulatory Framework, EPA Region, Location (State)	Purpose	Impacted Media, Contaminant(s)	Technologies Evaluated	Primary Driver and Status	Theme: Minimize/Eliminate Energy or Natural Resource Consumption	Theme: Harness/Mimic a Natural Process	Theme: Reduce/ Eliminate Releases to Environment, Especially Air	Theme: Reuse/Recycle Inactive Land or Discarded Materials	Theme: Use of Technologies that Permanently Destroy Contaminants	Triple Bottom Line: Environmental	Triple Bottom Line: Economic	Triple Bottom Line: Social	Reference or Source	Contact
Chambers Works - Solid Waste Management Unit 8	RCRA, State 2 (NJ)	Supported remedy selection	Waste and Soil Impacting Groundwater VOCs, SVOCs, metals	Excavation and disposal, *in situ* stabilization, *in situ* biodegradation	Remediation Proposed	X	X	X		X	X	X	X	David E. Ellis, DuPont	David.E.Ellis@usa.dupont.com
Confidential Former Electronics Manufacturing Facility	State 9 (CA)	Maximized reuse of demolition waste	Soil Petroleum hydrocarbons and VOCs	Chemical oxidation (*in situ* and *ex situ*), soil vapor extraction, lime stabilization	Remediation Implemented			X		X	X	X		Alan Leavitt, Northgate Environmental Management	alan.leavitt@ngem.com
Confidential Landfill	CERCLA 7 (Midwest)	Support remedy selection	Groundwater VOCs, SVOCs, metals	Groundwater collection (with and without a cut-off trench) and treatment, on-site and/or off-site treatment with subsequent on- and/or off-site disposal	Remediation Studied	X		X	X	X	X	X	X	Dave Hagen and Karin Holland, Haley & Aldrich	kholland@haleyaldrich.com
Dallas Naval Air Station	RCRA 6 (TX)	Select remedy for park development	Soil Pesticides	Cover in place	Remediation, Re-development Implemented	X		X	X		X	X	X	Allan Posnick, Texas Commission on Environmental Quality	posnick.allan@tceq.state.tx.us

(continued)

Exhibit 6-1. Continued

Site	Regulatory Framework, EPA Region, Location (State)	Purpose	Impacted Media, Contaminant(s)	Technologies Evaluated	Primary Driver and Status	Theme: Minimize/Eliminate Energy or Natural Resource Consumption	Theme: Harness/Mimic a Natural Process	Theme: Reduce/ Eliminate Releases to Environment, Especially Air	Theme: Reuse/Recycle Inactive Land or Discarded Materials	Theme: Use of Technologies that Permanently Destroy Contaminants	Triple Bottom Line: Environmental	Triple Bottom Line: Economic	Triple Bottom Line: Social	Reference or Source	Contact
Denver Federal Center	State 8 (CO)	Increase use of renewable energy for remediation, reduce sediment releases to storm water, reduce hazardous chemical use and the transfer of chemicals to other media, and re-develop site	Soil and Groundwater Trichloroethylene, PAHs, asbestos	Excavation, groundwater extraction, *in situ* chemical oxidation, monitored natural attenuation	Re-development Studied	X		X	X		X		X	Erik Petrovskis, GeoSyntec Consultants John Kleinschmidt, GSA	epetrovskis@geosyntec.com
De Sale Restoration Area	Voluntary 3 (PA)	Remediation of land	Surface Water Acid mine drainage, metals	Coal ash, settling ponds, vertical-flow ponds, and constructed wetlands to treat surface water	Remediation Implemented	X	X	X	X		X	X		EPA Technology News and Trends, Issue 37, July 2008	jayroberts@state.pa.us
Dover Air Force Base	CERCLA 3 (DE)	Investigate passive, bio-based technology versus pump and treat	Groundwater Chlorinated solvents	Biowall	Remediation Implemented		X	X	X	X	X	X		Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil
Fairchild Air Force Base	CERCLA 10 (WA)	Investigate passive, bio-based treatment system to achieve remedy in place	Groundwater Chlorinated solvents	Phytoremediation	Optimization Proposed		X	X			X	X	X	Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil
Ferdula Landfill	CERCLA, State 2 (NY)	Evaluated wind-driven vacuum processes vs. electrically powered air blowers for soil vapor extraction	Soil and Groundwater Toluene, trichloroethylene	Soil vapor extraction with carbon treatment	Remediation Implemented	X		X			X	X		David E. Ellis, DuPont	David.E.Ellis@usa.dupont.com

(continued)

Exhibit 6-1. Continued

Site	Regulatory Framework, EPA Region, Location (State)	Purpose	Impacted Media, Contaminant(s)	Technologies Evaluated	Primary Driver and Status	Theme: Minimize/Eliminate Energy or Natural Resource Consumption	Theme: Harness/Mimic a Natural Process	Theme: Reduce/ Eliminate Releases to Environment, Especially Air	Theme: Reuse/Recycle Inactive Land or Discarded Materials	Theme: Use of Technologies that Permanently Destroy Contaminants	Triple Bottom Line: Environmental	Triple Bottom Line: Economic	Triple Bottom Line: Social	Reference or Source	Contact
F.E. Warren Air Force Base	CERCLA 8 (WY)	Compared passive, bio-based technology to zero-valent iron and an electronic barrier	Groundwater Chlorinated solvents	Biowall	Remediation Implemented		X	X	X	X	X	X		Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil
Florence	State 4 (SC)	Supported remedy selection	Soil Chlorinated VOCs	Excavation and off-site disposal, zero-valent iron clay *in situ* treatment, excavation and off-site thermal oxidation	Remediation Implemented	X		X	X	X	X	X	X	David E. Ellis, DuPont	David.E.Ellis@usa.dupont.com
Former BP Refinery	RCRA, State VCP 8 (WY)	Worked with City of Casper to develop a cleanup strategy that could accommodate re-development of site, including commercial and multiple recreational uses	Soil and Groundwater BTEX	Pump and treat vs. groundwater pumping with engineered wetlands	Remediation, Re-development Implemented	X	X	X	X		X	X	X	EPA Technology News and Trends, Issue 36, May 2008	vmered@wyo.gov
Ft. Bliss Rod and Gun Club	RCRA 6 (TX)	Reclaimed contaminated soils	Soil Lead	Munitions recycling, soil reuse, mechanical and hand separation of lead bullet fragments, and lead bullet fragments reclamation	Remediation Implemented	X		X	X		X	X	X	Allan Posnick, Texas Commission on Environmental Quality	posnick.allan@tceq.state.tx.us
Hickam Air Force Base	CERCLA 9 (HI)	Investigate passive, bio-based solar-powered treatment system to achieve remedy in place	Soil and Groundwater Chlorinated solvents/leachate	In situ bioreactor	Remediation Proposed	X	X	X	X	X	X		X	Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil

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Remediation DOI: 10.1002.rem

Exhibit 6-1. Continued

						Theme					Triple Bottom Line				
Site	**Regulatory Framework, EPA Region, Location (State)**	**Purpose**	**Impacted Media, Contaminant(s)**	**Technologies Evaluated**	**Primary Driver and Status**	**Minimize/Eliminate Energy or Natural Resource Consumption**	**Harness/Mimic a Natural Process**	**Reduce/ Eliminate Releases to Environment, Especially Air**	**Reuse/Recycle Inactive Land or Discarded Materials**	**Use of Technologies that Permanently Destroy Contaminants**	**Environmental**	**Economic**	**Social**	**Reference or Source**	**Contact**
Maricopa	CERCLA 9 (AZ)	Feasibility study for technical and financial risk management	Soil Recalcitrant VOCs, LNAPL	Soil vapor extraction	Optimization Studied	X	X	X		X	X	X		Mike Reardon, GeoSyntec Consultants Lowell Kessell, Good EarthKeeping Organization	mreardon@geosyntec.com lkessel@envirologek.com

(continued)

Exhibit 6-1. Continued

						Theme					Triple Bottom Line				
Site	**Regulatory Framework, EPA Region, Location (State)**	**Purpose**	**Impacted Media, Contaminant(s)**	**Technologies Evaluated**	**Primary Driver and Status**	**Minimize/Eliminate Energy or Natural Resource Consumption**	**Harness/Mimic a Natural Process**	**Reduce/ Eliminate Releases to Environment, Especially Air**	**Reuse/Recycle Inactive Land or Discarded Materials**	**Use of Technologies that Permanently Destroy Contaminants**	**Environmental**	**Economic**	**Social**	**Reference or Source**	**Contact**
Martinsville	RCRA3 (VA)	Supported corrective measures study	Soil and Groundwater Chlorinated VOCs, BTEX, Freon®	Soil: *in situ* bioventing, enhanced biostimulation, passive bioventing, capping, off-site disposal, soil vapor extraction, excavation, off-site treatment, landfarm, *ex situ* thermal treatment, institutional controls, zero-valent iron clay Groundwater: pump and treat, constructed wetlands, phytoremediation, enhanced biostimulation, permeable reactive barrier, sparging, in-well stripping	Remediation Proposed	X	X	X	X	X	X	X	X	David E. Ellis, DuPont	David.E.Ellis@usa.dupont.com

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Remediation DOI: 10.1002.rem

Exhibit 6-1. Continued

Site	Regulatory Framework, EPA Region, Location (State)	Purpose	Impacted Media, Contaminant(s)	Technologies Evaluated	Primary Driver and Status	Theme: Minimize/Eliminate Energy or Natural Resource Consumption	Theme: Harness/Mimic a Natural Process	Theme: Reduce/ Eliminate Releases to Environment, Especially Air	Theme: Reuse/Recycle Inactive Land or Discarded Materials	Theme: Use of Technologies that Permanently Destroy Contaminants	Triple Bottom Line: Environmental	Triple Bottom Line: Economic	Triple Bottom Line: Social	Reference or Source	Contact
Massachusetts Military Reservation (CS-10)	CERCLA 2 (MA)	Optimize existing pump-and-treat system and monitoring network (sustainability assessment incorporated into the feasibility study)	Groundwater	No action, long-term monitoring, *in situ* chemical oxidation (pilot test), pump and treat	Optimization Studied	X		X		X	X	X	X	Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil
Massachusetts Military Reservation (Wind Turbine)	CERCLA 2 (MA)	Compared energy and air emissions by treatment systems to alternate energy source	Groundwater Ethylene dibromide and chlorinated solvents	Energy conservation, solar energy, wind energy	Optimization Implemented	X		X			X	X	X	Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil
McGregor Naval Weapons Industrial Reserve Plant	CERCLA 6 (TX)	Investigated passive, bio-based technology versus pump and treat	Groundwater Chlorinated solvents	Biowall	Remediation Implemented		X	X	X	X	X			Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil
Mountain View Manufacturing Area	CERCLA 9 (CA)	Support optimization evaluation	Soil and Groundwater Trichloroethylene and other VOCs	In situ oxidation and bioremediation, traditional and enhanced pump and treat, subsurface cutoff walls, permeable reactive barriers, deep soil mixing, excavation in the saturated zone, exposure point and institutional controls	Optimization Studied	X		X		X	X	X	X	Maile Smith, Northgate Environmental Management	Maile.Smith@ngem.com

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Exhibit 6-1. Continued

Site	Regulatory Framework, EPA Region, Location (State)	Purpose	Impacted Media, Contaminant(s)	Technologies Evaluated	Primary Driver and Status	Theme: Minimize/Eliminate Energy or Natural Resource Consumption	Theme: Harness/Mimic a Natural Process	Theme: Reduce/ Eliminate Releases to Environment, Especially Air	Theme: Reuse/Recycle Inactive Land or Discarded Materials	Theme: Use of Technologies that Permanently Destroy Contaminants	Triple Bottom Line: Environmental	Triple Bottom Line: Economic	Triple Bottom Line: Social	Reference or Source	Contact
Navy Exchange	State Action 4 (MS)	Evaluate sustainable remediation	Soil and Groundwater BTEX	Air sparging, excavation, and monitored natural attenuation	Remediation Studied	X		X			X			Isis Rivadineyra, Naval FESC	Isis.Rivadineyra@navy.mil
Oakley	RCRA, State 9 (CA)	Assess investigation options for carbon dioxide, energy, resource consumption, and exposure hours	Soil Tetrachloroethylene	Geophysics, test pits, passive absorbers, membrane interface probe, Geoprobe©, drill rig	Remediation Proposed	X		X			X		X	David E. Ellis, DuPont	David.E.Ellis@usa.dupont.com
Pompton Lakes	State 2 (NJ)	Support value engineering and remedy optimization for sustainability metrics	Sediment Mercury and lead	Hydraulic dredging, dry excavation, mechanical excavation	Remediation Studied	X	X	X			X		X	David E. Ellis, DuPont	David.E.Ellis@usa.dupont.com
Pueblo Army Depot	CERCLA 8 (CO)	Investigated passive, bio-based technology	Groundwater RDX	Biowall	Remediation Implemented		X	X	X	X	X	X		Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil
Reemay	State 4 (TN)	Evaluated pump and treat and stimulated bioremediation.	Groundwater Trichloroethylene	Pump and treat and enhanced bioremediation	Optimization Implemented	X		X		X	X		X	David E. Ellis, DuPont	David.E.Ellis@usa.dupont.com
Romic	RCRA 9 (CA)	Investigated alternate treatment technologies	Soil and Groundwater Trichloroethene	Capping, hydraulic containment, excavation and off-site disposal, *in situ* bioremediation	Remediation Approved	X	X	X		X	X			Karen Scheuermann, USEPA Region 9	scheuermann.karen@epa.gov
Seneca Army Depot	CERCLA 2 (NY)	Investigated passive, bio-based technology	Groundwater Chlorinated solvents	Biowall	Remediation Implemented		X	X	X	X	X	X		Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil

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Exhibit 6-1. Continued

Site	Regulatory Framework, EPA Region, Location (State)	Purpose	Impacted Media, Contaminant(s)	Technologies Evaluated	Primary Driver and Status	Theme: Minimize/Eliminate Energy or Natural Resource Consumption	Theme: Harness/Mimic a Natural Process	Theme: Reduce/ Eliminate Releases to Environment, Especially Air	Theme: Reuse/Recycle Inactive Land or Discarded Materials	Theme: Use of Technologies that Permanently Destroy Contaminants	Triple Bottom Line: Environmental	Triple Bottom Line: Economic	Triple Bottom Line: Social	Reference or Source	Contact
State Road 114 Ground Water Plume Superfund Site	CERCLA 6 (TX)	Augmented treatment of VOCs by soil vapor extraction system and air stripper with cryogenic compression and condensation technology to recover hydrocarbons	Groundwater 1,2-Dichloroethane, vanadium	Soil vapor extraction with thermal oxidation, activated carbon, or C-3 technology; air stripper off-gas with activated carbon	Optimization Implemented	X		X	X		X	X	X	Vince Malott, USEPA Region 6	malott.vincent@epa.gov
Tourtelot	State 9 (CA)	Establish open space and wetlands	Soil and Groundwater Ordnance, explosives, metals, petroleum hydrocarbons	Bioremediation, *in situ* treatment using mechanical mixers, mechanical removal, soil sifting, blow-in-place, excavation and disposal, spread and scan, geophysical scanning, recycling of metal debris, and blast chamber	Remediation Implemented				X	X	X	X	X	Alan Leavitt, Northgate Environmental Management Scott Goldie, Brooks Street James Austreg, California DTSC	alan.leavitt@ngem.com

(continued)

Exhibit 6-1. Continued

Site	Regulatory Framework, EPA Region, Location (State)	Purpose	Impacted Media, Contaminant(s)	Technologies Evaluated	Primary Driver and Status	Theme: Minimize/Eliminate Energy or Natural Resource Consumption	Theme: Harness/Mimic a Natural Process	Theme: Reduce/ Eliminate Releases to Environment, Especially Air	Theme: Reuse/Recycle Inactive Land or Discarded Materials	Theme: Use of Technologies that Permanently Destroy Contaminants	Triple Bottom Line: Environmental	Triple Bottom Line: Economic	Triple Bottom Line: Social	Reference or Source	Contact
Travis Air Force Base	CERCLA 9 (CA)	Investigate passive, bio-based solar-powered treatment system to achieve remedy in place	Soil and Groundwater Chlorinated solvents	*In situ* bioreactor	Remediation Proposed	X	X	X	X	X	X		X	Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil
Travis Air Force Base	CERCLA 9 (CA)	Reduce energy consumption for groundwater extraction at remote site	Groundwater Chlorinated solvents	Solar powered extraction pumps	Optimization Implemented	X		X				X	X	Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil
Travis Air Force Base	CERCLA 9 (CA)	Investigate of passive, bio-based treatment system to achieve remedy in place	Groundwater Chlorinated solvents	Phytoremediation	Optimization Proposed		X	X			X	X	X	Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil
Whiteman Air Force Base	CERCLA 5 (IL)	Investigated passive, bio-based technology	Groundwater Chlorinated solvents	Biowall	Remediation Implemented	X	X	X	X	X	X	X	X	Erica Becvar, AFCEE	Erica.Becvar@brooks.af.mil

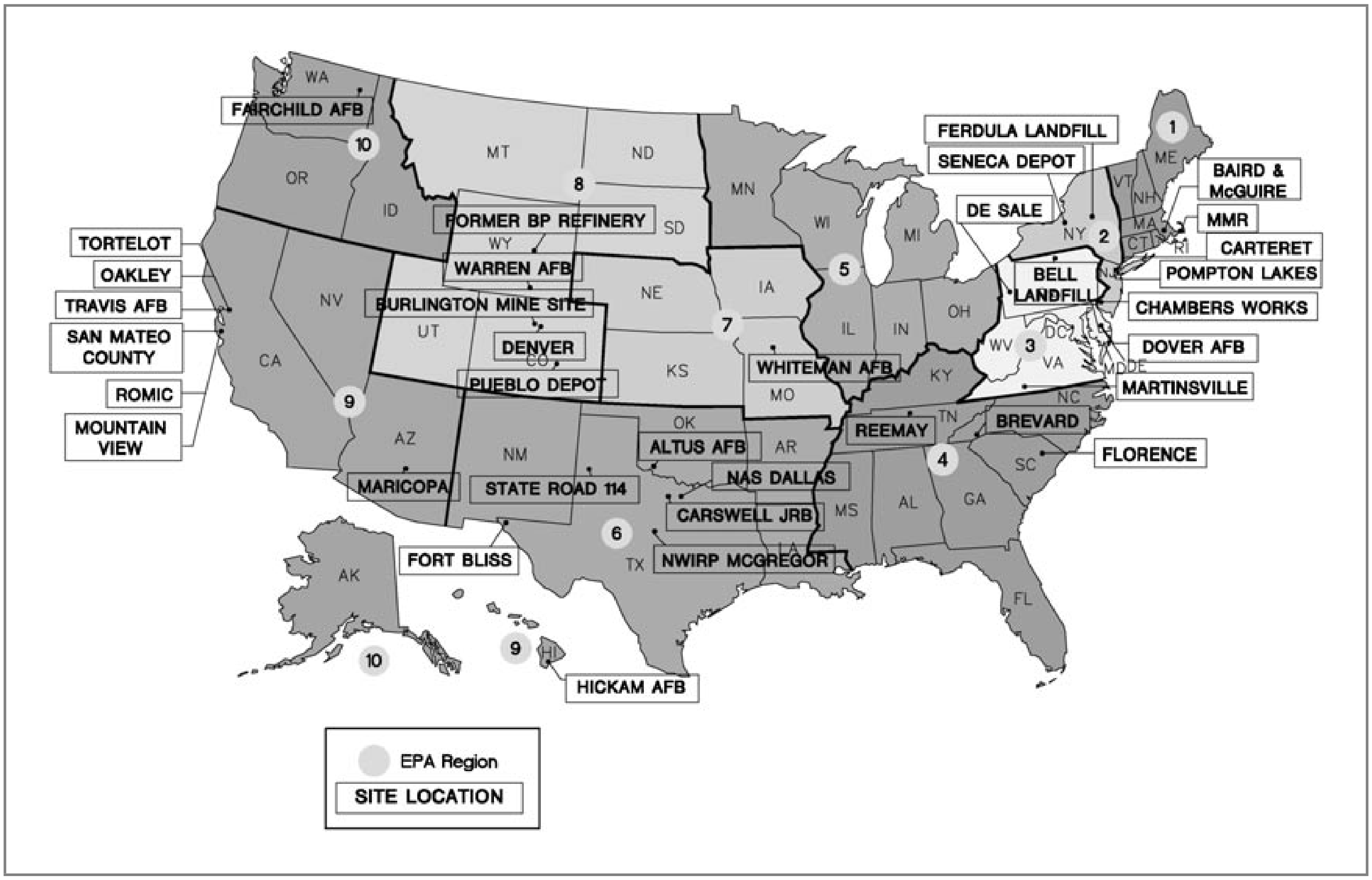

Exhibit 6-2. Sustainability assessments in the United States

recycling, remediation, or remedy optimization. Some assessments were conducted for internal study; other remedial selections that included sustainability have been proposed to and/or approved by regulatory entities. Many of the assessments have been implemented.

The assessments cover a variety of remediation activities, including pump-and-treat, soil vapor extraction, wetlands restoration, waste recycling, excavation, capping, *in situ* bioremediation, passive treatment, thermal remediation, and long-term monitoring. Contaminants or media addressed in the case studies include chlorinated solvents (including DNAPLs), metals, and petroleum hydrocarbons. Impacted media include landfill leachate, groundwater, soil, surface water, sediment, or a combination of more than one media.

Assessments and remedial action selections that include sustainability considerations have broad common attributes. Exhibits 6-1 and 6-3 identify the attributes considered, either explicitly or implicitly. The attributes are the degree to which the technologies achieve the following:

- minimize or eliminate energy or natural resource consumption;
- harness or mimic a natural process;
- reduce or eliminate releases to the environment, especially air;
- reuse or recycle inactive land or discarded materials; and
- permanently destroy contaminants.

Exhibit 6-3. Summary of international sustainability assessment examples

Site	Regulatory Framework, Location	Purpose	Impacted Media, Contaminant(s)	Technologies Evaluated	Primary Driver and Status	Theme: Minimize/Eliminate Energy or Natural Resource Consumption	Theme: Harness/Mimic a Natural Process	Theme: Reduce/ Eliminate Releases to Environment, Especially Air	Theme: Reuse/Recycle Inactive Land or Discarded Materials	Theme: Use of Technologies that Permanently Destroy Contaminants	Triple Bottom Line: Environmental	Triple Bottom Line: Economic	Triple Bottom Line: Social	Reference or Source	Contact
Railroad Tie Treatment Site	Provincial Order, British Columbia, Canada	Remedy selection	Sediments and Groundwater Dense Non-aqueous Phase Liquid	Pump and treat, caisson dredging, capping, risk assessment, sealed sheet pile wall and marsh construction	Remediation Studied	X	X	X	X		X	X	X	Stella Karnis, Canadian National, Don Bryant, Keystone Environment	stella.karnis@cn.ca
Rail Yard	Voluntary, Ontario, Canada	Multicriteria analysis tool.	Soil and Groundwater Diesel	Interceptor sumps, interceptor trench, multiphase extraction, hydraulic barrier, injection of oxygenated water	Optimization Studied	X		X		X	X	X	X	Stella Karnis, Canadian National, Robert Noel de Tilly, Golder	stella.karnis@cn.ca
Typical Gas Station	Study, Sweden	Assessment tool development	Soil BETX	On-site composting, off-site composting, In-situ aeration	N/A Studied	X	X	X			X	X	X	Lars Davidsson, WSP Environment & Energy, Halmstad, Sweden	lars.davidsson@wspgroup.se
Gela Plain, Sicily	Unknown, Italy	Feasibility Study	Soil TPH	Thermal desorption, ex situ landfarming, in situ landfarming, vertical barrier	Remediation Studied	X	X	X			X		X	Alessandro Battaglia, ENSR	abattaglia@ensr.aecom.com
Multiple: Manufactured Gas Plant, Waste Depository, Dry Cleaners	Various, Germany	Evaluate alternative technologies	Soil Chlorinated VOCs and BETX	Steam-enhanced SVE, conductive heating-enhanced SVE and "cold" SVE	Optimization Studied	X		X			X	X	X	Uwe Hiester, reconsite TTI GmbH ConSoil 2003 and 2005	uwe.hiester@reconsite.com

Exhibits 6-1 and 6-2 also recognize where various elements of the triple bottom line (as discussed in Section 5.1 and shown in Exhibit 5-4) were evaluated in the assessments.

As described in prior sections, some remedial measures tend to have lower impacts than others, especially when they incorporate the attributes listed above. However, due to site-specific factors, no single remediation technology can be considered more sustainable than others. While not explicitly considering sustainability, technologies harnessing natural processes (e.g., monitored natural attenuation, enhanced *in situ* bioremediation, phytoremediation, bioslurping, passive *in situ* treatment, bioventing, wetlands, bioreactors) are more energy- and resource-efficient. Their incorporation into an environmental restoration program generally results in a reduced or smaller impact. In addition, the assessments including some degree of life-cycle analysis enable consideration of the full cost or impact of the action.

The assessments summarized in Exhibit 6-1 were collected from consulting firms, site owners, the US EPA, various US EPA regions, state regulatory agencies, the Department of Defense (including the U.S. Air Force, Army, and Navy), and other regulatory entities. U.S. examples were the focus of the collection and assessment. Many non-U.S. assessments that include sustainability have been conducted. While not as extensive, Exhibit 6-3 summarizes several examples of assessments from the international environmental community.

6.2 Case-Study Summary

Remediation selection and optimization assessments using sustainability metrics have proliferated recently across the United States, as well as internationally. These assessments are beneficial where threshold criteria are met—that is, when human health and the environment are protected. Sustainability is never the sole criteria for remedy selection or optimization. The assessments, when combined with other balancing criteria, such as effectiveness and cost, produce more sustainable remedies.

Sustainability metrics have been used to inform remediation, redevelopment, optimization, and recycle projects. Many assessments that do not explicitly address sustainability themes (e.g., carbon footprint, energy) do embrace inherently sustainable practices and technologies (e.g., bioremediation, phytoremediation, biowalls). In addition, assessments "after the fact" are useful in developing protocols and fine-tuning assessment tools.

Remediation selection and optimization assessments using sustainability metrics have proliferated recently across the United States, as well as internationally.

6.3 Conclusions and Recommendations Drawn From Sustainability Assessments

The following conclusions were drawn after reviewing the assessments collected:

- Assessments that include sustainability can be used effectively to inform the selection and optimization of remedial actions.
- No uniform set of sustainability metrics has been used to conduct sustainability assessments.
- No clear guidance exists regarding sustainability assessment metrics and methodologies.

Based on these conclusions, the following recommendations are made:

- Sustainability assessments should be conducted as part of remedial action selection and optimization.
- Sustainability assessment methodologies should be flexible and permit the selection of metrics appropriate to site conditions and stakeholder values.
- Standardized criteria and guidelines for sustainability assessments should be developed.

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Remediation DOI: 10.1002.rem

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7.0 CONCLUSIONS AND RECOMMENDATIONS

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The current status and current practices of sustainable remediation have been discussed, along with the impediments and barriers. A vision for the future has also been presented. This section details the specific conclusions and recommendations based on the preceding sections of this document. Closing thoughts are also provided.

7.1.1 Sustainability Matters in Remediation

The remediation industry consumes a large amount of energy, generates large amounts of global warming gases as well as other air emissions, and creates measurable risk of injury and even death for its workers. Many of these impacts were not recognized as important when remedies were selected. Less apparent impacts (e.g., those made visible through an LCA) are, for the most part, not discussed, much less considered, when evaluating remedies. Both the obvious and nonobvious impacts of remediation are worth reducing, as would be expected for any other element of our economy that is the size of the remediation industry.

One key driver for sustainable remediation is the recognition by stakeholders that contaminated soil and groundwater cleanup can be labor-, energy-, and carbon-intensive. Therefore, some remediation projects by themselves can create a large environmental footprint if the project is implemented. Sustainable remediation principles and practices can help reduce the environmental impact of a particular project, as well as increase its net environmental benefit.

The remediation profession needs to consider sustainability principles and practices in all remediation-related activities. Site cleanup—from initial investigation through site closeout—is conducted by a significant-sized industry. Small gains at each step in the cleanup process can be summed at a global scale to contribute to reducing global warming gases and other environmental impacts.

7.1.2 Metrics Need to Be Developed and Consistently Used

The call for sustainability in remediation can only be productive when the stakeholders involved in decision making agree on what that means. This meaning can only be conveyed through metrics that can be used to identify, in some sense, a better or worse option or set of options.

In the two years of effort embodied in the production of this document, the call for establishing a set of metrics was a constant. At this juncture, there is no definitive list or all-encompassing set of parameters to consider. However, through discussion—particularly of assessments using sustainability metrics—SURF has identified and become familiar with a range of tools that have already found application. While most tools focus on quantifying energy consumption, greenhouse gases, and the carbon footprint of a remedy, other parameters related to air quality, the value of land and water, worker injury and loss of life, and nuisance conditions have been considered quantitatively in more sophisticated analyses. SURF proposes a sustainable remediation framework of 46 different best practices in sustainable remediation. These best practices can be a first step toward identifying sustainability metrics.

Remediation DOI: 10.1002.rem

More of this kind of effort is necessary to provide as much consensus as possible on how to identify key metrics, how to measure or estimate them, and how to evaluate those measurements in decision making.

7.1.3 Progress Is Necessary at All Levels

Remediation programs in the government and the private sector are very much entrenched and invested in energy-intensive remedies. Public stakeholders also value action over the potential environmental consequences of not applying energy-intensive remedies. For technical professionals, progress at a basic level would require that sustainability principles be incorporated into the traditional conceptual site model. For nontechnical people involved in remediation (e.g., administrators, financial officers, community stakeholders, elected officials), this would include identification of sustainability principles in the various steps for a cleanup, such as flowcharts, with some format for clearly indicating the potential environmental consequences of various choices and approaches.

While some regulatory agencies are moving toward implementing sustainability principles and practices in remediation, these changes would be visible and might meet resistance. Clearly, a commitment to make progress is necessary from those in positions of authority. Change management practices should be adopted so that all stakeholders understand the benefits of change while at the same time minimize perceived threats to the status quo.

7.1.4 More Case Studies Are Needed

While some regulatory agencies are moving toward implementing sustainability principles and practices in remediation, these changes would be visible and might meet resistance.

SURF has compiled a case study of assessments that use sustainability metrics. This case study shows how remediation professionals in relative isolation from one another have nonetheless championed the cause of sustainability in remediation. These assessments have encouraged, inspired, guided, and educated others, and have served as convincing examples that it can be accomplished. The case study demonstrates that sustainable remediation assessments have been performed in numerous states and many US EPA regions at various scales to varying degrees in all environmental matrices and addressing a myriad of contaminants.

A compilation of case studies aimed at deliberately evaluating key metrics—in design as well as performance of remedies—needs to be undertaken. The effort should also evaluate the barriers encountered, the surrounding regulatory framework, and where the principles were addressed at what basic levels. Such a task is particularly well suited to be accomplished by academia and federal research and development organizations. SURF has initiated this effort. Section 6.0 contains the most comprehensive collection of sustainability assessments currently available.

7.1.5 Slower Is Sometimes Better

The laws of chemistry and physics control the rates of remediation. These constraints cannot be wished or legislated away. A fundamental tenet of remediation, loosely based on scientific principles, is that active remediation with intensive energy consumption will likely go faster than less energy-intensive and passive approaches. However, the overall net environmental impacts of a slower or passive approach may be far less.

The amount of energy necessary to change chemical or physical rates is very high. The desire for rapid cleanup should be balanced with other factors. In fact, energy-intensive remediation efforts have not been substantially more successful than lower-intensity efforts (NRC, 2005).

Until there is a wide demand for remediation systems that demonstrably and reliably achieve cleanup objectives, sustainability will struggle to find its role in remediation. Clearly, such systems will have to rely on sound science and engineering.

Until there is a wide demand for remediation systems that demonstrably and reliably achieve cleanup objectives, sustainability will struggle to find its role in remediation.

7.1.6 Perception Is Important

The public, elected officials, legal industry, lending institutions, media, and others spend an inordinate amount of time dealing with perceptions associated with contaminated sites. There are instances of sustainable remedies being preferred over more energy-intensive and environmentally impacting remedies. The sustainability assessments in this report provide examples. However, at present, these examples are relatively few and far between. How to change the basic perceptions about contaminated sites that have developed over the last several decades is a significant challenge.

7.1.7 Leadership From Beyond SURF Will Be Necessary

There is no doubt that contaminated properties come with a perceived stigma: exaggerated perceptions about the potentially harmful conditions associated with the property that are held by the public, media, regulatory agencies, financial institutions, and other organizations. Although SURF can work on tangible barriers that are measurable in some fashion, there are also invisible barriers (e.g., perceptions and sometimes vested interests) that cannot be measured or addressed by SURF but that must be considered.

SURF is working to further the implementation of sustainability principles and practices in remediation. However, for a politically visible person to support a slower and more sustainable remediation approach anywhere—much less everywhere—would be difficult.

At some point, there needs to be visible leadership from beyond the membership of SURF, likely by a person or organization within a state or federal regulatory agency, to encourage sustainability to reach its full potential in the remediation industry.

7.1.8 Sustainability Means Change

Most organizations and regulatory entities in the remediation industry, both in government and outside of government, have developed approaches, attitudes, and practices over the last 30 years that might be described as well worn. Sustainability challenges many, if not most, of those approaches, attitudes, and practices. In describing barriers, the most basic barrier—resistance to change—is apparent. In as costly, contentious, and litigious an industry as remediation, making positive changes of any kind is difficult, but the change in basic approaches that are inherent in considering sustainability could be quite slow to come about in some organizations.

While a number of regulatory organizations have encouraged and furthered the incorporation of sustainability principles and practices into remediation projects, sustainability is generally not a required criterion for decision making. Oftentimes, the

Remediation DOI: 10.1002.rem

incorporation of new concepts happens as the result of champions who must work to overcome the inertia associated with preferences for energy-intensive remedies. Several regulatory entities are involved in initiatives or pilot projects to explore the prospects of incorporating sustainability into remedial decision making. However, at present, there is no formal framework for incorporating sustainability into the decision-making process. While the prospects are good that sustainability will eventually be formally considered in remedy selection, there is no guarantee on either an organizationwide or case-by-case basis.

SURF members serve as champions for incorporating sustainability principles and practices in their everyday work and through outreach opportunities. Clearly, these individuals believe that the changes inherent in incorporating sustainability into remedial decision making are changes for the better.

7.1.9 Sustainable Practices Can Be Incorporated at Any Stage

Many energy- and resource-intensive remedies have been operating for years, even decades. Quite often, these remedies are not evaluated for effectiveness, much less sustainability. Such remedies are prime candidates for process optimization, including reevaluation of not only performance, but also sustainability.

Because there are a very large number of existing remedies, even small improvements in efficiency that reduce carbon footprints and lessen the draw on energy and other resources would collectively have a significant effect. These remedies offer good opportunities for the before vs. after comparisons favored in case studies. There is no reason to wait to apply sustainability principles and practices for only new projects. Current projects, many of which should be undergoing routine audits and evaluations, are prime candidates for lessening the environmental burden of remediation.

SURF members suggest that sustainability may be an effective tool for sensibly harmonizing the current discrepancies in how different organizations (particularly regulatory agencies) devoted to the same goals differ quite widely when it comes to remedy selection.

7.1.10 Working Together Is a Necessity, Not an Option

SURF has found that by working together the progress made has been collectively far greater than the sum of the individual efforts of its members. SURF's efforts have been linked to other similar national and international initiatives, and the learning curve has been accelerated for all parties. At this juncture, it is necessary for a coordinated effort among local, state, and national initiatives venturing to integrate sustainability concepts into remediation. The consequences of not working together should be viewed in the status quo for other elements of the remediation industry (e.g., risk assessment, institutional controls, and remedy selection) where jurisdiction-by-jurisdiction approaches have led to significant discrepancies in practice and effect.

SURF members have been motivated to work together in part because of the current state of affairs where huge discrepancies are apparent between how different regulatory programs approach and affect cleanups—especially the differences between programs in the same agency. To this end, SURF members suggest that sustainability may be an effective tool for sensibly harmonizing the current discrepancies in how different organizations (particularly regulatory agencies) devoted to the same goals differ quite widely when it comes to remedy selection.

7.2 Recommendations

7.2.1 Think Beyond the Fence Line

The traditional approach of remediation has been to focus on the task of removing contaminants from soil and groundwater. While such undertakings do not always measurably improve the public health and the environment, the energy and effort expended trying to accomplish such goals have impacts beyond the fence line. Equipment such as trucks used to haul contaminated soil, energy used to pump and treat groundwater, and fans running as part of vapor extraction systems all consume resources and energy, have worker safety concerns, and lead to environmental impacts beyond the fence line. Those impacts need to be important to all participants in a remediation project and need to be considered as a part of the remedy evaluation, design, selection, and implementation.

Academia should accept the challenge to train the next generation of engineers and scientists entering the remediation industry in the principles and practices of sustainability.

Everyone needs to begin thinking about the consequences of remediation that will occur beyond the fence lines. Thinking about and eventually taking action to reduce impacts beyond the fence line will establish the paradigm shift needed to implement sustainability principles and practices in remediation. Remediation proposals should document impacts at the site, locally, regionally, and globally.

7.2.2 Increase Academic Participation

Researchers in academia have worked on a wide range of sustainability issues—from building greener buildings to choosing more sustainable materials and manufacturing practices for everyday activities. Academia has developed highly sophisticated analytical methods to conduct sustainability studies in a range of areas and has developed expertise that should cross over rather easily to similar issues in the remediation industry. In addition, faculty may approach the problem from a more balanced perspective than either regulators or the regulated community.

Academia should accept the challenge to train the next generation of engineers and scientists entering the remediation industry in the principles and practices of sustainability. Government and industry should fund substantive research into the sustainability of remedial actions. Government, industry, and professional organizations should develop standards of sustainability practice and widely disseminate those through training.

7.2.3 Develop a Regulatory Framework

Several regulatory entities are involved in initiatives or pilot projects to explore the prospects of incorporating sustainability into remedial decision making. While a number of regulatory organizations have encouraged and furthered the incorporation of sustainability principles and practices into remediation projects, sustainability is generally not a required criterion for decision making. At the present time, there is no formal framework for incorporating sustainability into the decision-making process. Regulatory authorities need to recognize simply but visibly that sustainability principles and practices lead to better remedies.

 Remediation DOI: 10.1002.rem

Regulatory authorities need to establish a mechanism for allowing sustainability into decision making in a formal and transparent way. Now is the time for regulatory authorities to actively engage SURF and effectively move ahead by formally defining and accepting sustainability principles and practices.

7.2.4 Standardize and Adopt Valuation Criteria and Metrics

At present, there are no centralized sources of information or standard approaches for integrating sustainability principles and practices into remediation projects. Much of the effort to standardize sustainability is happening in an ad-hoc fashion. Individual companies and organizations are developing their own tools and resources. However, without a strong effort to standardize these currently separate efforts, it is likely that progress will be spotty and hard-won.

Regulators and the remediation industry need to develop a standard set of valuation criteria and metrics that can be used in remedial decision making and operation.

7.2.5 Compile and Publish Case Studies

Case studies included in this document indicate that stakeholders have considered and integrated sustainability principles—often qualitatively but increasingly quantitatively—in remediation projects. Those who are charged with formally and transparently integrating sustainability principles into remedial decision making will undoubtedly ask for demonstrated value and efficacy. This challenge is most easily met by compilation of case studies, an exercise that has been invaluable for SURF.

A standard approach should be developed for evaluating before-and-after conditions of existing projects being retrofit or for evaluating with and without conditions for projects undergoing planning. Otherwise, it will be difficult to say if consideration of sustainability is beneficial in the first place, much less how significant it might be in the long run for any particular remediation project.

The US EPA would be respected and valued in leading this evaluation. SURF suggests that it could also be accomplishable by entities that have historically served as neutral parties on new environmental matters and issues (e.g., the NRC).

Regulators and the remediation industry need to develop a standard set of valuation criteria and metrics that can be used in remedial decision making and operation.

7.3 Closing Thoughts

The systems of selecting remedial actions that are used today were created more than 30 years ago. At that time, these systems represented the best knowledge and best practices available. A very large number of remedial actions have now been implemented, a great deal of academic research has been completed, and a great deal of practical experience has been gathered by the remediation industry. In an era where global warming has become an increasing concern, the remediation profession is learning that not only do current remediation methods use unnecessary amounts of energy, but they also can contribute too much carbon dioxide, release other greenhouse gases, release ozone-depleting substances, and create risks to remediation site workers that far exceed the risk posed by the contaminants being removed or destroyed.

This accumulating realization leads remediation professionals to an increasingly strong belief that they can be active participants in solving the world's contamination problems.

Carefully including sustainability in the evaluation of remediation projects will address many of these growing concerns. Sustainability will require the evaluation of off-site effects at the local, regional, and global scales.

A fair means of balancing the different kinds of impacts is needed. For example, at this time there is no accepted method that allows for the evaluation of the relative risks due to contaminants against the risks due to the construction and operation of a remediation. A neutral body such as the NRC should be charged with developing a fair and practical risk-balancing method.

When substantial upgrades are proposed in the way that environmental decisions are made, the appropriate stakeholders need to be brought into the discussion before those changes are put in place. Identifying and inviting these stakeholders to participate should be accomplished by federal and state agencies.

Now is the right time for regulatory entities to formally include sustainability criteria in the system for evaluating and selecting remedial actions. At the same time, we should take a balanced look at whether all the existing criteria truly contribute to making good decisions. If existing decision criteria for remediation do not clearly contribute to making good decisions, now is the time to make the changes necessary to correct that situation.

The need for action is here today and will only increase by tomorrow.

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DISCLAIMER

This document was produced by the Sustainable Remediation Forum, a voluntary organization with broad membership. The content of and the views expressed in this document are solely those of the authors and of SURF and do not reflect the policies or views of any SURF member corporations or organizations.

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Remediation DOI: 10.1002.rem