Technology Overview

Green and Sustainable Remediation: State of the Science and Practice

May 2011

Prepared by
The Interstate Technology & Regulatory Council
Green and Sustainable Remediation Team

ABOUT ITRC

Established in 1995, the Interstate Technology & Regulatory Council (ITRC) is a state-led, national coalition of personnel from the environmental regulatory agencies of all 50 states and the District of Columbia, three federal agencies, tribes, and public and industry stakeholders. The organization is devoted to reducing barriers to, and speeding interstate deployment of, better, more cost-effective, innovative environmental techniques. ITRC operates as a committee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers. More information about ITRC and its available products and services can be found on the Internet at www.itrcweb.org.

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- * notable writing contributions
- † took a leadership role during document production
- § multiyear active member of the team

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EXECUTIVE SUMMARY

Numerous initiatives are taking place in the field of green and sustainable remediation (GSR). In this technology overview document, the Interstate Technology & Regulatory Council (ITRC) GSR Team introduces the concept of GSR and charts its current status. By providing some basic definitions and describing the approaches of different agencies, states, and other entities, the GSR Team aims to help educate and inform state regulators and other stakeholders in the concepts and challenges of GSR. One of the greatest challenges of GSR is the current lack of consensus on applying measures of sustainability. In this document, the GSR Team summarizes current definitions and tools available to help users incorporate sustainability factors into site management decision making. There is no industry-wide consensus on the definitions of the term "green and sustainable"; therefore, discussions on this area may not be addressing consistent concepts. This document is meant to be not guidance, but rather a discussion of ideas as they currently appear to exist. It is expected that these concepts, definitions, and tools will continue to rapidly evolve. This overview is a companion document to the GSR Team's forthcoming technical and regulatory guidance document.

The development and evolution of hazardous waste statutory and regulatory authorities and years of experience in site remediation have produced an established process for remedy selection and implementation based on protection of human health and the environment. Some past practices have resulted in remedies for which green or sustainable aspects were not often considered; rather, if a remedial action considered green or sustainable elements, it was often as an afterthought. The federal government, states, industry, and academia have all been hard at work developing more comprehensive approaches to consideration of green remedial measures as part of environmental restoration, thus making the development of this document timely. Green remediation is not a stand-alone concept but is rather part of the overall remedial process to protect human health and the environment. A global focus on assessing the causes of climate change and a collective growing awareness of the potential adverse impacts of energy-intensive remediation systems have resulted in an increasing array of directives and orders to minimize the impact of the remedial environmental footprint, prompting the investigation and implementation of GSR approaches.

Many federal and state-lead cleanup programs have begun to consider how remedial actions could lower their environmental footprint. This is considered "greening" the cleanup or a green remediation, whereas a sustainable cleanup would go further to consider economic and social aspects. Most practitioners understand that sustainability involves three basic aspects, including environmental, economic, and social considerations. Sustainability may be considered on a scale from local to global effects of the remedy, depending on the boundaries identified during the GSR planning process. This idea is discussed further in the planning section of the forthcoming technical and regulatory guidance document.

Remedy decisions need to be made in the context of the regulatory scheme within which the remedy is being conducted. For example, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Resource Conservation and Recovery Act (RCRA) programs have a regulatory process, and consideration of green remediation may be part of remedy selections. Remedy decisions consider remedy cost and reasonably anticipated land use as part of the alternatives development and remedy selection. More expansive concepts of social and economics are generally not part of the remedy selection process under CERCLA but may influence state and community acceptance, which is considered in remedial alternative analyses. Remedies may often be implemented in ways that take into consideration social and economic perspective.

The ITRC GSR Team envisions that greener remedies are a natural extension of these established programs that can be considered as part of the remedial action process. There is a clear need to implement remedies in a way that minimize the environmental footprint, and while efforts to advance that goal are moving rapidly on many fronts, understanding what is meant by the term "sustainable" is an ongoing effort. That effort includes identifying opportunities for ensuring that remedies support the needs of the community.

While program-specific regulatory criteria do not address the broader societal and macroeconomic considerations, programs operating under the National Oil and Hazardous Substances Pollution Contingency Plan may allow for implementation of many sustainability measures. Potential limitations to the inclusion of green remediation within the CERCLA and RCRA regulatory framework are being identified and discussed, especially with regard to the nine criteria currently applied to the standard remedy selection process. The U.S. Environmental Protection Agency (EPA) is presently clarifying the role of green remediation within the context of these criteria and believes that most green remediation measures fit nicely within the existing criteria. EPA emphasizes that, while the evaluation of economic and social aspects of sustainability of remediation is valuable and can help inform the overall course of cleanup, specific inclusion of these aspects may exceed the authority of current regulatory programs.

This document presents GSR concepts that can provide consistency in application and consideration of GSR during the site-management process. By approaching GSR as an improved site-management process, impacts to human health and the environment can be effectively addressed, while considering how to maximize social and economic benefits, thereby making GSR a logical extension of the evolving remedial action process.

The GSR Team urges caution regarding the usage of GSR language and terminology, which is under development across organizations and generalized in nature. A variety of terms are being used, and care must be taken in using these terms specific to any program areas, such as CERCLA.

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1. INTRODUCTION

In the context of this document, "remediation" is the abatement, cleanup, or use of a variety of other methods to contain, remove, and/or destroy contaminants of concern from the environment to protect human health. A remediation project typically consists of multiple stages, including planning, investigation, assessment of remedial alternatives, remedy selection, remedy design, and construction and implementation of the chosen remedy, often followed by years of operation and maintenance and site management. A remediation project may also proceed to subsequent site restoration and redevelopment to support the beneficial reuse of the site. Remediation projects are typically subject to an array of regulatory and other stakeholder requirements. Historically, these requirements have focused on human health and a limited number of different environmental risks to inform the remedy selection process. Consistent with the regulations, remediation needs to consider human health and environmental impacts that include the environmental footprint of the remedy. A more holistic approach is increasingly being applied during the remediation life cycle, namely the integration of "green and sustainable remediation" (GSR).

"Green remediation" is the practice of considering all environmental effects of remedy implementation and incorporating options to minimize the environmental footprints of cleanup actions (EPA 2010b). Essentially, green remediation is the incorporation of environmental best management practices (BMPs) that may be employed during a project, while "sustainable" approaches may consider those emerging techniques that are both economical and capable of achieving significant environmental and social benefits.

GSR is broadly defined in this document by the Interstate Technology & Regulatory Council (ITRC) GSR Team as a remedy or combination of remedies whose net benefit to human health and the environment is maximized through the judicious use of resources and the selection of remedies that consider how the community, global society, and the environment would benefit, or be adversely affected by, remedial investigation and corrective actions. This document applies GSR best practices throughout the remediation life cycle from release detection through remedial action completion. Protection of human health and the environment is still of paramount importance, as well as complying with federal, state, and local regulations; however, GSR principles factor into consideration a range of environmental issues and community impacts aimed at maximizing the environmental, social, and economic considerations as appropriate. Under some cleanup authorities, this approach may involve consideration of economic aspects with ecological and social benefits in the decision-making process.

The incorporation of GSR principles and practices into remediation is evolving, coinciding with the growth and maturation of the remediation industry. Fundamentally, remediation is inherently focused on protecting human health and the environment; however, recent advances in understanding risks associated with remedy implementation and risks posed by the remedies themselves has provided changing perspectives on how to implement remedies to minimize the environmental footprint. Remediation professionals are considering how best to design site investigation and remedial processes with an eye toward implementing green remediation and GSR approaches. In addition, GSR techniques can be used to optimize older remediation systems, ensuring the protectiveness of the remedy while increasing the efficiency of the contamination containment/removal.

The selection of a remedy or alternative has historically been determined by the type of contaminant and media affected, the location and characteristics of the cleanup site, and the potentially exposed receptors and available cleanup technologies, combined with applicable state and federal regulations. Under current regulatory frameworks, indicators of the success of an environmental remediation project can potentially externalize many of the impacts associated with remedial actions. However, it is becoming increasingly clear that there is a real need to consider other factors that embrace GSR principles and practices so as to reduce the environmental footprint, cost, and community impacts of a remedy. GSR includes consideration of the environmental, economic, and social aspects associated with the entire life cycle of the environmental cleanup project.

In an effort to advance the field of environmental remediation and consider how it may fit with long-term sustainability, this document summarizes the current state of GSR. It also identifies sources of additional information needed to educate and train state regulators and other stakeholders.

An important aspect of defining and advancing the understanding of GSR approaches is the confusion that exists with the terms "green remediation" and "GSR." The authors of this document believe that there are three main factors contributing to the lack of clarity with terminology. First, statutory and regulatory authorities currently governing cleanups enacted in the 1980s do not explicitly recognize sustainability principles as balancing factors (in the case of Comprehensive Environmental Response, Compensation, and Liability Act [CERCLA] sites) or corrective action design. Second, many organizations in the United States and in other countries are drafting various, albeit reasonably similar, definitions and policies, all of which are unique and serve differing purposes. Third, the two distinct, yet related terms, "green" and "sustainable" are often used interchangeably. This document addresses each of these issues.

Another important aspect of this effort is that, due in part to the present statutory and regulatory climate, the U.S. Environmental Protection Agency (EPA) is focused on green remediation aspects of the GSR approaches described in this document. The EPA comments on an earlier draft of this overview document noted that not all the macroeconomic and societal components in this document may be accommodated under the CERCLA remedy selection criteria and thus may not be applicable to National Priorities List (NPL), NPL equivalent, and federal facility sites. EPA further noted that these components may not be used as a tenth balancing factor to the existing nine criteria when selecting CERCLA remedial actions.

This document focuses on identifying the meaning of comprehensive GSR and capturing the range of implementation efforts through local and worldwide organizations. The methodologies for incorporating GSR will be addressed in the GSR Team's forthcoming technical and regulatory guidance document.

2. DEFINITIONS

The terms “green” and “sustainable” have several evolving definitions. This section outlines a number of key terms in use by a variety of leading GSR organizations. A compilation of definitions offered by those organizations is provided for the following critical terms:

- green
- sustainable
- green remediation
- sustainable remediation
- green and sustainable remediation

In addition, this section clarifies the meaning of each term as it is used in this document.

2.1 Green

Although there is no single definition of “green,” a broad definition is “being environment-friendly or beneficial to the environment” (Vilsack 2009). “Green” solutions generally improve the environment and/or use fewer natural resources. In general, the production or performance of “green” processes, products, technologies, and procedures are favorable compared to other options; that is, they have a more positive impact on their local or global surroundings, at a specific time, than other possible alternatives. The term “green” does not necessarily imply a net benefit to the environment from a holistic perspective (e.g., a product that uses less energy but generates more waste could potentially be described as “green”).

2.2 Sustainable

“Sustainable” is a general concept with a wide array of existing definitions, mostly oriented toward subcomponents of sustainability like sustainable development and sustainable employment. Common themes include the holistic consideration of environmental, social, and economic impacts of an activity and evaluation of these impacts on the future. Existing definitions include the following:

- The traditional definition of sustainability calls for policies and strategies that meet society’s present needs without compromising the ability of future generations to meet their own needs (EPA 2010a).

- Sustainable development “meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development 1987).

- “To create and maintain conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations” (Executive Order 13514, 2009).

- “The capacity to continue [the Air Force’s] mission without compromise. It is the ability to operate into the future without decline—either in the mission or the natural and man-made systems that support it. Sustainability is ensuring viable missions, while respecting the resources that support them: human, financial, and the natural and built environments" (AFCEE 2004).

- A strategy that "simultaneously meets current as well as future mission requirements world-wide, safeguards human health, improves quality of life, and enhances the natural environment" (U.S. Army 2004).

- "Sustainable practices are those that consider economic and natural resources, ecology, human health and safety, and quality of life" (NAVFAC 2009).

- Sustainable development can be defined as "improvement of human life within the carrying capacity of supporting ecosystem" (World Wildlife Fund).

- EPA definition of sustainable: "Today EPA aims to make sustainability the next level of environmental protection by drawing on advances in science and technology, applying government regulations and policies to protect public health and welfare, and promoting green business practices" (EPA 2010a).

In a broader context, sustainability is an attempt to provide the best outcome in which the diversity and quality of our surroundings are maintained or even improved, providing the capacity to support the human and natural environment, the potential to adapt to future changes, and the maintenance of a wide range of choices and opportunities for the future. Sustainability includes the assessment and valuation of temporal effects, including the extent to which limited resources may continue to be used effectively and beneficially in the future. These impacts and benefits can also be viewed in the context of a life-cycle assessment of different remediation alternatives.

2.3 Green Remediation

"Green remediation" refers to the use of environmentally conscious practices and approaches at any stage in the site cleanup process to maximize net benefits for the environment. According to EPA, green remediation is the practice of considering all environmental effects of remedy implementation and incorporating options to minimize the environmental footprints of cleanup actions (EPA 2010b).

Green remediation approaches typically use BMPs to reduce the impact of a remedial action on the environment. Examples include the following:

- conserving natural resources
- using environmentally friendly products
- reducing, reusing, and recycling materials
- protecting and optimally using natural resources
- minimizing energy use, increasing energy efficiency, and using renewable energy
- reducing air emissions of dust, volatile organic compounds (VOCs), nitrogen oxides (NO_x), sulfur oxides (SO_x), and greenhouse gases (GHG)

- managing storm water and wastewater, controlling erosion and sediment accumulation, and minimizing impacts on water resources
- designing treatment systems to provide optimum efficiency
- using renewable resources such as wind and solar energy to meet power demands of treatment systems
- generating electricity from by-products such as methane gas or secondary materials
- participating in power generation or purchasing partnerships based on renewable resources
- minimizing fresh-water consumption and maximizing water reuse during treatment processes
- preventing impacts such as nutrient loading on water resources
- reclaiming treated water for beneficial use such as irrigation or for storage through aquifer reinjection

2.4 Sustainable Remediation

"Sustainable remediation" refers to an integrated assessment of the environmental, economic, and social impacts of remedial activities. Existing definitions include the following:

- "A remedy or combination of remedies whose net benefit on human health and the environment is maximized through the judicious use of limited resources" (Hadley and Ellis 2009).

- The practice of demonstrating, in terms of environmental, economic, and social indicators, that an acceptable balance exists between the effects of undertaking remediation activities and the benefits that those activities deliver (SuRF-UK 2009).

- "Sustainable practices result in cleanups minimizing the environmental and energy 'footprints' of all actions taken during a project life" (EPA 2008b).

Sustainable remediation considers a range of environmental issues and community impacts and integrates economic, ecological, and social implications into the consideration of the collateral impacts of investigation and remediation activities. In addition to the techniques listed previously under green remediation, sustainable remediation may also consider the following:

- impacts of site remediation on the surrounding community/region that are both economic and social (e.g., job loss/creation, tax revenue from redevelopment of brownfield sites)
- effects on public health associated with remediation activities
- improved public health and safety through environmental remediation
- social benefits of site restoration activities (e.g., environmental justice and other equity issues, increased adaptability)
- improved education, skills, values, and leadership capacity of individuals and/or the community
- economic incentives for various remedial options/activities
- economic implications of carbon emissions/sequestration as a result of site remediation
- economic implications of changes in resource value as a result of site remediation (e.g., habitat loss/creation)

- social implications of end land use (e.g., increased social inclusion and interaction, security, and adaptability)

Sustainable remediation recognizes the social and economic context of the site. By recognizing three aspects of sustainability—namely, environmental impacts, economic viability, and social impacts—sustainable remediation goes beyond environmental stewardship through site restoration and revitalization.

2.5 Green and Sustainable Remediation

“Green and sustainable remediation” is a term that collectively describes various remedial approaches, ideas, and practices of green remediation and sustainable remediation. The following is an existing description of GSR:

> Green and sustainable remediation expands upon the Department [of Defense]’s current environmental practices and employs strategies for cleanups that use natural resources and energy efficiently, reduce negative impacts on the environment, minimize or eliminate pollution at its source, protect and benefit the community at large, and reduce waste to the greatest extent possible. Green and sustainable remediation uses strategies that consider all environmental effects of remedy implementation and operation and incorporates options to maximize the overall environmental benefit of cleanup actions (DOD 2009).

The ITRC GSR Team offers another definition:

> A scalable method for evaluating and implementing green and sustainable elements beyond traditional decision-making factors. This scalable method can be applied at any or multiple point(s) in the cleanup process, thus allowing the user the ability to identify, evaluate, balance, and quantify environmental, economic, and social aspects. The GSR process should help users identify factors and elements they may want to consider and provide an approach for maximizing the short- and long-term social, economic, and environmental goals under various cleanup programs while continuing to protect human health and the environment.

Both EPA’s definition of “green remediation” and the Sustainable Remediation Forum (SURF) definition of “sustainable remediation” have generated significant dialogue regarding what is “green” and what is “sustainable.” This dialogue has greatly enhanced the evaluation and reevaluation of traditional and innovative remedial approaches, including the metrics by which remedial options have been or may be measured. Frame-of-reference plays a significant role in identifying and measuring what is “green” or “sustainable” to stakeholders concerned with environment, human health, and cost. Ideally, both “green” and “sustainable” concepts will be evaluated and, to the greatest extent possible, be integrated into remediation projects, to result in a net benefit to local and global environments, societies, and economies.

Accordingly, the GSR Team will provide an integrated and consensus-based definition of “green and sustainable remediation” in its forthcoming technical and regulatory guidance document that will offer a common reference for the environmental remediation community. The following draft definition will likely be modified as the document is developed:

> Green and sustainable remediation is a spectrum standard for site-specific employment of products, processes, technologies, and procedures that mitigate contaminant risk to receptors while making decisions that are cognizant of balancing net environmental effects, community goals, and economic impacts.

While the definitions described in this chapter capture the fundamental tenets of green and sustainable remediation, they are subject to interpretation by the user depending on the context in which they will be implemented. The application of GSR concepts is in its infancy and is still highly variable across the United States. As the state of the science rapidly evolves and green and sustainable standards are further developed at all levels of government, these definitions will be refined.

Also, the GSR Team notes that, while no specific technology or method can be exclusively called or claimed to be a "green technology" or "green methodology," some aspects of them can be greener. Regulators, site owners, and other stakeholders should be cautioned about such claims and be judicious in selecting appropriate remediation methods at their sites.

2.6 Social Aspect of Green and Sustainable Remediation

This document provides several definitions of green, sustainable, and green and sustainable remediation. These definitions clearly state that the application of GSR approaches should demonstrate, in terms of environmental, economic, and social indicators, the effects of the remedial action and the benefits the same activities will deliver. Environmental indicators are readily available and customarily used; economic indicators are also readily available and often used to some extent, although much work is needed to capture the true cost of remedial actions, including all externalities. The development of tools that address the social aspects of sustainable practices is lagging behind the development of tools in the other two areas of sustainability. Societal acceptance, benefits, and impacts are generally more difficult to define; however, certain social indices can be considered appropriate to remediation activities.

Some of these indices are linked to environmental and economic measures. Certain societal considerations are site and location specific, and quantifying these requires direct feedback from stakeholders in the form of surveys, focus groups, or meetings. The EPA Office of Superfund Remediation Technology Innovation (OSRTI) launched an effort to address the lack of guidelines in the existing Superfund decision-making protocols for consideration of the social, cultural, and economic impacts (Galisteo Consulting Group 2004). The results of the study were quite clear: understanding the sociocultural impacts of EPA's processes and actions can reduce antagonistic working relationships, increase community involvement, and facilitate negotiations and selection of remedies that are consistent with community needs, all of which are at the core of sustainable remediation practices. Issues to be addressed in assessing social aspects include impacts on human health and safety; ethical and equity considerations; impacts in neighborhoods and/or regions; community involvement and satisfaction; compliance with policy objectives; and strategies, uncertainty, and evidence.

Ultimately, the output of an assessment of the social component of a remedial action is expected to be mainly qualitative rather than quantitative. Combined with the limitations of the present statutory and regulatory setting and the lack of specific expertise on social implications among environmental practitioners, these issues present significant barriers to more widespread use of social considerations in the planning for and implementation of remedial systems.

2.7 Green and Sustainable Remediation and Regulatory Framework

Though there are no regulations that specifically govern the GSR process, there are provisions in several existing regulations where GSR principles are directly applicable. Remediation must meet the substantive requirements of existing laws, regulations, and policies. Many of the principles and practices of GSR reflect the concerns that are addressed by existing substantive legal requirements such as discharge and emission criteria, tracking and appropriate disposal of waste shipments, wetland replication requirements, BMPs pertaining to dust and noise abatement, worker safety and exposure limits, and natural resource restoration. The implementation of GSR principles and practices should be accompanied by a careful assessment of the compliance requirements of the existing environmental legal framework and coordination with any requirements to avoid duplication, redundancy, and potential conflict.

2.7.1 Federal Programs

Federal regulatory program are focused on the protection of human health and the environment. The following federal statutes may apply to site cleanups:

- Clean Water Act
- National Environmental Policy Act
- Rivers and Harbors Appropriations Act
- Clean Air Act
- Endangered Species Act
- Resource Conservation and Recovery Act (RCRA)
- National Historic Preservation Act
- Office of Safety and Health Administration
- Comprehensive Environmental Response Compensation and Liability Act
- Solid Waste Disposal Act
- Small Business Relief and Brownfields Revitalization Act

Many states have been authorized to implement one or more of the above regulatory programs and may have adopted a state program that is broader in scope or more stringent than the federal requirements.

2.7.2 State Programs

State regulatory programs are focused on protection of human health and the environment. To that end, state regulatory site decisions will maintain a similar central focus as GSR policies or procedures are developed and put in place. State programs, including leaking underground storage tank (LUST), voluntary and brownfields cleanup programs, closed landfill, and other programs, can incorporate GSR concepts to the degree they can be implemented in accordance with corresponding policy and regulatory frameworks. Certain state programs may find that integration of GSR approaches enhances site management decisions, decreases remediation timeframes, decreases overall cleanup costs, and incorporates community outreach and communication. Those programs funded by state funds should consider communication not only with the funders (e.g., LUST reimbursement programs) but also with brownfields grant funding organizations. At the state and county level, these organizations provide the opportunity to incorporate GSR concepts into their grant applications and reimbursement processes.

State-lead cleanup projects may find the greatest potential in assimilating GSR concepts due to the leveraging control they have over site-specific work practices, contract requirements, and reporting requirements.

2.7.3 Incorporation of CERCLA and RCRA Remedy Selection Criteria

In general, CERCLA and RCRA programs, as well as other program areas, have room for inclusion of GSR considerations under existing conditions and the development of a broader adoption of BMPs that incorporate GSR principles. For example, there are nine existing criteria that pertain to remediation under CERCLA and provide the framework to implement GSR. The nine criteria include two threshold criteria: (1) the overall protection of human health and the environment and (2) compliance with applicable, relevant, and appropriate requirements; five balancing criteria: (3) long-term effectiveness and permanence, (4) reduction in toxicity, mobility, and volume, (5) short-term effectiveness, (6) implementability, and (7) cost; and two modifying criteria: (8) state acceptance and (9) community acceptance. Substantial work is proceeding within EPA to identify how green and sustainable remediation practices can be incorporated into the Superfund process and to promote the development and broader adoption of BMPs that incorporate GSR principles and result in a minimized environmental footprint as appropriate.

3. INVENTORY OF GSR-RELATED EFFORTS

During the period when this document was under development, green remediation policies and white papers continued to be developed, and GSR practices continued to be implemented. Over the same period, various entities advanced sustainable remediation by developing approaches that consider environmental actions for impacted sites along with economic considerations and social aspects. Green remediation policies are being implemented, while comprehensive GSR is slowly developing and gaining acceptance. International organizations and countries have developed some of the underlying premises on which GSR policies and programs in the United States are based. Many of these are focused on green remediation—reducing emissions, conserving natural resources, and using BMPs to do things more efficiently. This section identifies a number of the organizations involved with the development of green remediation or GSR policies and practices, including state, federal, military, and private entities and international groups. It should be noted that this inventory is expected to change substantially as GSR knowledge, acceptance, and implementation continue to evolve and the GSR Team completes its technical and regulatory guidance document.

3.1 State Regulatory Authorities

This section provides descriptions of a number of state programs that are advancing green remediation or GSR programs through the development of policy and/or guidance documents and tools. The following descriptions show that these programs are in various stages of development and that the states are each addressing GSR in a unique manner.

3.1.1 Illinois Environmental Protection Agency Matrix

The Illinois Environmental Protection Agency Bureau of Land developed a matrix to emphasize greener cleanups. Based on five guiding principles, this matrix helps maximize the environmental benefits of site remediation. Using a two-tiered approach, a simple matrix and an expanded matrix are created based on the complexities of a particular site. Mind maps and decision trees are developed for LUST sites to guide these sites through required actions to achieve greener cleanups.

Following are the five guiding principles of the Illinois Green Remediation program:

1. Ensure every cleanup protects human health and the environment.
2. Integrate site reuse plans into the cleanup strategy.
   a. Sequence work to improve efficiency.
   b. Make use of engineered barriers and institutional controls that are compatible with future site development.
3. Conserve raw materials such as soil and water; salvage building materials and other resources.
   a. Reduce waste disposal.
   b. Reduce the need for new materials, including clean fill and potable water.
   c. Use existing infrastructure.
4. Conserve energy.
   a. Reduce energy consumption.
   b. Use renewable energy sources to power cleanup activities where possible.
5. Consider the environmental effects of treatment technologies when choosing a site remedy.
   a. Compare options for contaminant disposition (permanent destruction, pollutant transfer or management in place).
   b. Evaluate resources demand.
   c. Assess long-term stewardship responsibilities.

3.1.2 Wisconsin's Initiative for Sustainable Cleanups (WISC)

WISC is a new initiative within the Remediation and Redevelopment Program of the Wisconsin Department of Natural Resources (WDNR) to emphasize the applicability of sustainable technologies in site remediation by saving energy, reducing GHGs, and minimizing waste through reuse and recycling. By developing a Sustainable Remediation Reference Guide, WISC will provide guidance to WDNR staff for baseline sustainability reviews for proposed remediation systems and provide a framework for comparing outcomes from various sustainable elements on individual remedial projects.

WISC has identified specific goals, including the following:

- maximize use of shrinking state Environmental Fund and bonding money
- reduce GHGs and long-term global impacts
- reduce energy usage
- reduce and recycle materials; use "green" construction
- make sustainability a standard component of state-funded projects
- encourage public/private partnerships
- reinvent approach to state-funded projects and the program in general
- effectively manage WDNR staff workload with existing resources
- expand WISC
- involve Green Tier Charter/Environmental Management System

The WISC Program will be described in a guidance document to be issued by WDNR in the spring of 2011.

3.1.3 Minnesota

The Minnesota Pollution Control Agency (MPCA) has addressed the emerging topic of greener cleanups through a focused initiative termed "Green Sustainable Remediation and Redevelopment" (GSR2). As part of the initiative, the Petroleum Remediation Program (PRP) formed the Green Remediation Implementation Team (GRIT) in March 2009 in response to EPA recommendations for implementing green practices at projects funded by the American Reinvestment and Recovery Act (ARRA). GRIT's initial goals were predicated on the five core elements of the Greener Cleanups Initiative promulgated by EPA Office of Solid Waste and Emergency Response (OSWER) (EPA 2008a).

GRIT was formed with the intent to be inclusive of cleanup as well as redevelopment approaches to GSR2. Within GRIT, remediation is not intended to be done in a "green" manner without being cognizant of the ultimate goal of reuse of the property. Sustainable redevelopment is one of the cornerstones of this effort as the MPCA drives toward integrated guidance for GSR2 across Remediation Division programs. GRIT produced guidance for green practices for use during ARRA projects. The PRP directed its multisite contractors to use the documents in preparing their ARRA project proposals. The proposed green practices were evaluated and scored. The "green" score was weighted and used in the overall contractor selection process.

The GRIT green practices were implemented in phases and allowed the contractors to expand on the ideas and technologies provided. Upon completion of ARRA-funded project work, GRIT will document the effectiveness of the implemented green practices to develop guidance that prevents or minimizes "green-washing." Those practices will be enhanced and integrated throughout the MPCA Remediation Division.

3.1.4 California

California Department of Toxic Substances Control (DTSC) formed its Green Remediation (GR) Team in February 2007 to promote the use of green considerations in site investigation and cleanup. DTSC has defined GR as "the application of technologies and approaches that enhance a cleanup project's environmental, social, and economic footprints. It is a holistic approach that incorporates sustainability concepts and life-cycle thinking over a broad scope and time horizon" (DTSC 2007). Through its GR initiative, DTSC has shown how sustainability and life-cycle thinking can be incorporated into any stage of a remediation project, including the site characterization, treatment alternative selection, remedial design implementation, and continuing through long-term operations and maintenance and closure. DTSC's GR team has developed an Interim Advisory for Green Remediation (December 2009), hosted a one-day symposium on the Global Perspectives on Green Remediation–Making Clean "Green" (February 2009), and created a qualitative tool called the Green Remediation Evaluation Matrix (GREM).

DTSC's website provides the following definition for GR:

> Because the materials used and the energy consumed in a cleanup impacts beyond the site, the environmental footprint of a cleanup activity exceeds the site's physical boundary. GR assessments identify potential impacts that may have been discounted, or not included, in traditional assessments, and address those that occur on local, regional, and global scales. It includes the direct and indirect releases of contaminants, the consumption of raw materials, the production, collection, and disposal of wastes. These assessments will also include social and economic impact analyses, such as analyses of noise or visual nuisance impacts upon the community that could be mitigated by early stakeholder involvement in the planning process, or the consideration of opportunities for employment and job training by members of low-income communities that may be adjacent to or affected in the past by the contaminated site (i.e., environmental justice).

DTSC's interim advisory is intended for project managers, responsible parties, and environmental consultants performing sustainability or GR assessments at cleanup sites. DTSC's GR Team prepared it to introduce the concepts of sustainability and life-cycle thinking and how these concepts can be incorporated into any stage of a cleanup project, from site characterization through site closure. The advisory also introduces GREM, which is a simple Excel-based tool for qualitative comparisons of treatment alternatives. The matrix can be completed for a site, documenting the release of pollutants and waste (including air pollutants and GHGs), physical disturbances and disruptions (such as noise and traffic), and resource depletion or gain. To address the limitations of the GREM, such as its qualitative nature, DTSC provides a toolbox of resources that can be used for calculating GHG emissions, energy consumption, and life-cycle assessments. DTSC plans to periodically update the advisory to include state-of-the-art quantitative and qualitative assessment techniques.

The advisory states that DTSC "recognizes that sustainability, while not explicitly listed as one of the nine criteria set forth in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), should be considered as one of several factors to be examined in evaluating the impact of a remedy." Some of these factors may compete with sustainability, and trade-offs may become necessary to achieve the best approach or most acceptable solution for the stakeholders. The elements of GSR that require activities to provide additional protection of natural resources beyond what is required for remediation may result in redundancy and potentially be in conflict with existing regulatory frameworks.

Under CERCLA and the NCP, natural resource damage (NRD) assessments are completed within three years of the remediation. These assessments recognize that value of the lost natural resources and provide for compensation to the trustees. The NRD mechanism provides incentive for restoration and/or compensation for compromised natural resources. The assessment tools discussed in the advisory (including GREM) provide an opportunity for stakeholders to evaluate the impact of a remediation project on valuable natural resources before a remedy is selected.

3.1.5 Alabama

Environmental investigations conducted by the Alabama Department of Environmental Management (ADEM) or facilitated through state regulatory oversight are encouraged to incorporate sustainable and green remedial practices. Whether corrective action is required through the Clean Air Act, Clean Water Act, Drinking Water Act, or under federal solid and hazardous waste laws, sustainability of the remedial system is included in the decision-making process. Also, green practices are assessed to reduce waste and promote conservation during the remedial process. Although sustainable and green remediation is encouraged, the practices are not mandated under existing program requirements, and a matrix tool has not been adopted. The ADEM Land Division does, however, assess remedial sustainability during RCRA Corrective Action, CERCLA feasibility studies, and in aboveground storage tank remediation. At these steps in the regulatory process, the sustainability of remedial alternatives is evaluated for long-term effectiveness, performance, implementability, and cost. ADEM currently incorporates procedural measures on a case-by-case basis to gauge the effectiveness and sustainability of remediation.

3.1.6 New York

The New York State Department of Environmental Conservation’s Division of Environmental Remediation (DER) issued a Proposed Program Policy for Green Remediation (DER-31) on March 17, 2010, that identifies its preferred approach to remediation as one which more consistently implements GSR concepts and practices while meeting minimum remedial program requirements and remaining protective of human health and the environment. The policy references EPA documents, including the “green remediation primer” (EPA 2008a). Other recent DER guidance indicates that GSR concepts will be expected and encouraged in all phases of remediation to promote environmental stewardship and beneficial reuse. DER program staff will be responsible for implementation of the DER-31, with input from other divisions.

DER developed the policy to be applied to the entire life cycle of the site remediation process from investigation, through remedial design and construction, to long-term site management and operation of remedial systems. The policy will be applied as new remedial sites are identified and during relevant phases of work at existing sites in state remedial programs.

The proposed policy recognizes that the greatest potential for beneficial evaluation and implementation of GSR can be accomplished during the remedy selection process; therefore, the process will require review of sustainable options as part of the remedial alternatives analysis. Specifically, climate impacts, GHG emissions, and renewable energy are identified as key environmental impacts that will likely require additional analysis during the feasibility study process. DER-31 indicates that the greenest remedies will be preferred, which are likely to be those that minimize short- and long-term ancillary impacts to the environment; minimize the carbon and environmental footprint of the remedy; achieve the remedial action objectives more sustainably; achieve a complete and permanent cleanup; and permanently and significantly reduce the toxicity, mobility, or volume of contamination. The document clearly indicates that GSR will not be used to rationalize lesser remedies when a more appropriate and feasible remedy is available.

DER-31 does not specify methods or criteria to be used to quantify the effectiveness of the various GSR concepts or remedial alternatives, citing the site-specific nature of the evaluation process and indicating that all information presented will be considered. DER-31 cites the following GSR concepts, which may be considered for each remedial project to the extent feasible to foster economically sound and environmentally sustainable cleanups and provide general examples of GSR techniques that can be applied under each (Attachment 1 to DER-31):

- considering the environmental impacts of treatment technologies and remedy stewardship over the long term when choosing a site remedy
- reducing direct/indirect greenhouse gas and other emissions
- increasing energy efficiency, using renewable energy sources where possible, and minimizing use of nonrenewable energy
- conserving and efficiently managing resources and materials
- reducing waste, increasing recycling and increasing reuse of materials that would otherwise be considered waste
- maximizing habitat value and creating habitat when possible
- fostering green and healthy communities and working landscapes that balance ecological, economic, and social goals
- integrating the remedy with the end use where possible and encouraging green and sustainable redevelopment

The program policy will require supporting documentation for all proposed and successfully executed GSR efforts, as follows:

- Remedial alternatives analyses and decision documents must include descriptions of all GSR principles considered during remedy selection, including qualitative or quantitative supporting data.

- Final engineering reports must include descriptions and documentation of the GSR practices employed during the remedial program.

- GSR concepts and principles will require consideration during each periodic review and remedial system optimization review performed during site management. Reports will detail the GSR techniques employed during the previous reporting cycle, will provide information on impact reductions to the environment, and will provide recommendations to be implemented during the next reporting cycle.

3.1.7 Massachusetts

The Massachusetts Department of Environmental Protection (MassDEP) has stated that it considers it a high priority to identify opportunities to promote energy conservation and renewable energy use. In November 2009, MassDEP launched a website that highlights GSR principles and provides information on GSR in MassDEP cleanup programs, information on incentives and energy efficiency, and other resource links to organizations that are focusing on GSR opportunities: www.mass.gov/dep/cleanup/priorities/susrem.htm. MassDEP will be posting information on successful case studies where GSR principles were implemented.

The MassDEP Bureau of Waste Site Cleanup (BWSC) policy for state-managed facilities and state-funded cleanups is to assess emissions associated with remediation, implement energy efficiency, and explore innovative technologies as well as renewable energy use. State contracts include language preferring the use of sustainable and green technologies and practices. The framework of MassDEP's cleanup program is considered broad enough to support GSR in advance of more specific program development.

To support the effectiveness of the state privatized cleanup program (Massachusetts General Laws, Chapter 21E) and to address sustainable operations, the MassDEP BWSC has developed an electronic data viewer application, eDEP. This is a secure site for submitting environmental permits, transmittals, certifications, and reports electronically to MassDEP. With eDEP, the user can fill out forms online, save work, return to them later; submit forms online; submit over-the-counter payments electronically online; "sign" submittals; and print out receipts of transactions. Prior to the development of eDEP, all submittals were provided to MassDEP in paper form and would usually be retrieved and reviewed at state offices.

In addition to numerous benefits for the user from eDEP, the added sustainable benefits of using the electronic system include elimination of paper use, reduction of file storage space, and reduction of fuel use travelling to and from MassDEP offices to review files. This system is a first of its kind in the United States in which electronic submittals are available for retrieval within minutes to regulators, submitters, and the general public.

3.2 Federal Government

On October 5, 2009, President Obama issued Executive Order (EO) 13514, *Federal Leadership in Environmental, Energy, and Economic Performance*. This EO applies to the operations of the federal government and therefore to many federally operated or funded remediation projects and programs, one of the key drivers in the rapid rise of awareness about green remediation technologies and practices. The EO states that, "federal agencies shall increase energy efficiency; measure, report, and reduce their greenhouse gas emissions from direct and indirect activities; conserve and protect water resources through efficiency, reuse, and storm water management; eliminate waste, recycle, and prevent pollution; leverage agency acquisitions to foster markets for sustainable technologies and environmentally preferable materials, products, and services; design, construct, maintain, and operate high performance sustainable buildings in sustainable locations; strengthen the vitality and livability of the communities in which Federal facilities are located; and inform Federal employees about and involve them in the achievement of these goals."

3.2.1 U.S. Environmental Protection Agency

In April 2008, EPA published the document *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* (EPA 2008a). This "green remediation primer" provides EPA's overview of green remediation and established EPA's core elements of green remediation, consisting of energy, air, water, land and ecosystems, materials and waste, and stewardship. The primer also addresses important aspects of green remediation, including regulatory requirements and site management practices such as site investigation and monitoring, air quality protection, water quality protection and conservation, ecological and soil preservation, and waste management. As stated in the primer:

> As part of its mission to protect human health and the environment, the EPA is dedicated to developing and promoting innovative cleanup strategies that restore contaminated sites to productive use, reduce associated costs, and promote environmental stewardship. EPA strives for cleanup programs that use natural resources and energy efficiently, reduce negative impacts on the environment, minimize or eliminate pollution at its source, and reduce waste to the greatest extent possible in accordance with the EPA's strategic plan for compliance and environmental stewardship (EPA Office of the Chief Financial Officer 2006). The practice of "green remediation" uses these strategies to consider all environmental effects of remedy implementation for contaminated sites and incorporates options to maximize the net environmental benefit of cleanup actions.

Increasing concerns regarding climate change have prompted major efforts across the globe to reduce GHG emissions caused by activities such as fossil fuel consumption. EPA's current strategic plan calls for significant reductions in GHG emissions as well as increases in energy efficiency as required by federal mandates such as EO 13423 (*Strengthening Federal Environmental, Energy, and Transportation Management*, 2007) and EO 13514.

One category of EPA's evolving practices for green remediation places emphasis on approaches that reduce energy consumption and GHG emissions, such as designing treatment systems with optimum efficiency and modifying them as needed, using renewable resources such as wind and solar energy to meet power demands of energy-intensive treatment systems or auxiliary equipment, using alternate fuels to operate machinery and routine vehicles, generating electricity from by-products such as methane gas or secondary materials, and participating in power generation or purchasing partnerships offering electricity from renewable resources.

In an August 2009 policy message, OSWER Assistant Administrator Marty Stanislaus cited his "Greener Cleanup Principles":

1. Consistent with existing laws and regulations, it is OSWER policy that all cleanups
    - protect human health and the environment
    - comply with all applicable laws and regulations
    - consult with communities regarding response action impacts consistent with existing requirements
    - consider the anticipated future land use of the site

2. The following five elements of a green cleanup assessment may assist in the evaluation and documentation used in selecting and implementing protective cleanup activities:
   - total energy use and renewable energy use
   - air pollutants and GHG emissions
   - water use and impacts to water resources
   - materials management and waste reduction
   - land management and ecosystems protection

3. As tools are developed and deployed, when it is feasible to use greener cleanup approaches, OSWER cleanup programs will document how these five elements were considered and implement best practices to reduce the environmental footprint of cleanups. The nature of greener cleanup assessments can vary with the complexity of the site, program and community priorities and the availability of tools. Assessment activities should be performed in a transparent manner involving the community and other stakeholders and describe how the programs have considered the items described in (1) and (2) above.

4. OSWER will evaluate progress in reducing the environmental footprint of protective cleanups.

5. Greener cleanup approaches span multiple cleanup programs and reflect a developing set of practices. Legal authorities differ by cleanup program, environmental issues and community priorities differ from region to region and site to site, and greener cleanup best practices and assessment tools are at the early stages of development and testing. Greener cleanup approaches, therefore, may vary from site to site and program to program and will continue to evolve by incorporating lessons from the growing state of knowledge.

Assistant Administrator Stanislaus clarified that OSWER cleanup programs should consider these greener cleanup principles during any phase of work, including site investigation; evaluation of cleanup options; and optimization of the design, implementation, and operation of new or existing cleanups. All cleanup approaches and all elements of the cleanup process can be optimized to enhance their overall environmental outcome; therefore, green remediation involves more than merely adopting a specific technology or technique.

The Assistant Administrator went further to say that these greener cleanup principles are not intended to allow cleanups that do not satisfy threshold requirements for protectiveness or do not meet other site-specific cleanup objectives to be considered greener cleanup. The principles are not intended to trade cleanup program objectives for other environmental objectives. Successful green cleanup practices can help achieve cleanup objectives by ensuring protectiveness while decreasing the environmental footprint of the cleanup activity itself. Some examples include using equipment that emits less particulate matter to the air; sizing equipment accurately to avoid wasted energy, water, and material; and using renewable energy or recycled material to decrease GHG emissions and conserve resources.

EPA’s regulatory programs and initiatives actively support site remediation and revitalization that result in beneficial reuse such as commercial operations, industrial facilities, housing, greenspace, and renewable energy development. The EPA has begun examining opportunities to integrate sustainable practices into the decision-making processes and implementation strategies that carry forward to reuse strategies. In doing so, EPA recognizes that incorporation of sustainability principles can help increase the environmental, economic, and social benefits of cleanup. In the context of CERCLA, however, economic and social benefits of cleanup are not threshold or balancing criteria and may not be used to modify or diminish the protectiveness of cleanups.

Opportunities to reduce the environmental footprint of a cleanup exist in all phases of the cleanup cycle, including investigation, design, construction, operation, and monitoring, regardless of the selected cleanup remedy. As cleanup technologies continue to advance and incentives evolve, green remediation strategies can significantly increase the long-term effectiveness of cleanup, reduce project costs, and expand the available options for long-term property use or reuse without compromising cleanup goals.

Green remediation strategies are rooted in the concept that economic development is ecologically viable over the short and long term, without foregoing environmental protection. EPA has compiled information from a range of its programs that supports advancement of sustainable principles along the categories of the built environment; water, ecosystems, and agriculture; energy and environment; and materials and toxics.

In August 2009, EPA published *Superfund Green Remediation Strategy* for public comment. This document specifically addresses how green remediation applies to and can be implemented under the Superfund Program. The final strategy (EPA 2010c), published September 30, 2010, contains an appendix of 30 key implementation actions designed to integrate green cleanup principles widely within the Superfund program. The Superfund Remedial Program is dedicated to the cleanup of the nation's uncontrolled hazardous waste sites. As stated in *Superfund Green Remediation Strategy*, "Since its inception in 1980, Superfund (which includes the OSRTI, the Federal Facilities Restoration and Reuse Office [FFRRO], the Federal Facilities Enforcement Office [FFEO], the Office of Site Remediation Enforcement [OSRE], the Office of Emergency Management [OEM], and EPA regional Superfund offices) has made considerable progress toward cleaning up hazardous waste sites and responding to emergencies involving hazardous substances." *Superfund Green Remediation Strategy* sets out current plans of the Superfund Remedial Program to reduce GHG emissions and other negative environmental impacts that might occur during remediation of a hazardous waste site or non-time-critical removal actions.

Further, the strategy states, "In September 2008, OSRTI formed a workgroup of headquarters and regional staff to develop a green remediation strategy that could reduce the environmental footprint of Superfund response actions taken at private and federal sites which at the same time protects human health and the environment. The Strategy is not intended to be a comprehensive or static document; rather, it will change over time as we learn more about how to improve cleanup activities."

Superfund Green Remediation Strategy (EPA 2010c) outlines nine key action items and recommends related activities to promote green remediation. The action items and recommendations are organized into three categories: policy and guidance development, resource development and program implementation, and program evaluation. Under each key action item, the strategy lists specific tasks that are being initiated, are under development, or have been completed.

In developing these action items, the workgroup highlighted several needs that are important to the implementation of green remediation:

- clarify how green remediation practices fit within the CERCLA and the NCP
- improve the understanding of potential resource and energy demands for many Superfund remedies
- develop a consensus on metrics that can be used to measure and evaluate green remediation actions

Superfund Green Remediation Strategy (EPA 2010c) includes a series of program initiatives to expedite pursuit and use of green remediation strategies and contains recommendations to develop white papers that clarify major issues such as the extent to which OSRTI, FFRRO, FFEO, OSRE, and Superfund regional programs can incorporate green remediation practices under existing laws and regulations. The strategy also includes a recommendation to pursue follow-on directives that help foster greater use of green remediation practices at Fund-lead (i.e., sites where cleanup is funded and led by EPA), state-lead, potentially responsible party–lead, and federal facility sites.

The strategy includes a series of program initiatives to expedite pursuit and use of green remediation practices:

- maximize use of renewable energy with a goal of using 100% renewable energy to power site operations and identify methods for increasing energy efficiency
- incorporate green remediation factors as part of remedy optimization evaluations starting in fiscal year 2010
- pursue ways to reduce the use of natural resources and energy during remedial actions and when developing cleanup alternatives
- integrate clean, renewable, and innovative energy sources and advanced diesel technologies (such as diesel particulate filters and alternative fuels) and encourage operational practices (such as engine idle reduction practices) to minimize total emissions
- establish tools to track and increase potable water conservation, the reuse of treated water, and recharge of aquifers
- identify additional on- or off-site uses of materials or energy otherwise considered waste
- include language in statements of work for removal action, remedial design, and remedial action procurement contracts that specifies use of green remediation practices and requires separate reports for energy/fuel usage and costs
- help communities establish networks and training programs that enable local workers (including minority and low-income populations) to gain proficiency in expertise needed for green cleanups, such as energy efficiency auditing and renewable energy applications

Finally, the strategy includes a key action to establish a process for quantifying achievements regarding the program’s commitment to reduce the demands that site cleanups place on the environment. OSRTI will collect and use regional summaries, site-specific data, and trend information to establish a solid baseline on the environmental demands made prior to strategy implementation. Using this baseline, the program will establish performance goals, objectives, and measures for the Superfund Green Remediation Strategy.

The strategy document states, “As a ‘living’ document, OSRTI will update the Strategy to reflect refined Agency policy, modified activities within the key actions, and other developments as green remediation matures. EPA is seeking input from Superfund ‘stakeholders’ including affected communities, state and local governments, tribal governments, other federal agencies, cleanup contractors, principal responsible parties, and developers. The Agency will conduct specific outreach activities to solicit and promote input on further refining this Strategy and focusing this effort.”

As part of its efforts to advance green remediation throughout its programs, EPA has created and maintains a webpage on its www.cluin.org site specifically focused on green remediation and providing a wide variety of information, including BMPs and how to implement them during the site remediation process, reference documents, policies and strategies, site profiles, upcoming events, and news. In addition, EPA provides its Remedial Project Managers (RPMs) with eight hours of training in the area of green remediation through the National Association of Remedial Project Managers.

The following is a sample of green remediation efforts under development:

- memoranda of understanding with the National Renewable Energy Laboratory and the U.S. Army Corps of Engineers (USACE)
- fostering green remediation BMPs at Superfund cleanups, green remediation analyses, development of footprint calculation methodologies (Region 9)
- remedy-specific green remediation “Fact Sheets”
- a site cleanup energy audit tool
- a “Who’s who?” in green remediation (EPA intranet)
- Engineering Forum “Green Remediation Review and Technical Support” capability
- Green Cleanup Voluntary Standards Project

In a related development, EPA is preparing a national optimization strategy that will capitalize on the technical support provided to over 150 NPL sites to create further efficiencies within the Superfund Program. This strategy incorporates green remediation as a major optimization component throughout the CERCLA investigation, remedy selection, and remedial implementation process.

EPA sponsors the Federal Remediation Technologies Roundtable (FRTR), which works to build a collaborative atmosphere among federal agencies involved in hazardous waste site cleanup. FRTR was established in 1990 to bring together top federal cleanup program managers and other remediation community representatives to share information and learn about technology-related efforts of mutual interest, discuss future directions of the national site remediation programs and their impact on the technology market, interact with similar state and private industry technology development programs, and form partnerships to pursue subjects of mutual interest. FRTR member agencies include U.S. Department of Defense (DOD), U.S. Air Force, U.S. Army, U.S.

Navy, U.S. Department of Energy (DOE), U.S. Department of the Interior, EPA, and the National Aeronautics and Space Administration. Since its inception, collaborative efforts among the FRTR member agencies have led to technology development and demonstration partnerships with private developers, a more consistent and unified federal approach to technology evaluation and regulatory acceptance, and a variety of technology transfer tools and other information resources. GSR-related efforts are being actively considered and discussed in FRTR.

3.2.2 U.S. Department of Defense

On August 10, 2009, DOD issued a memorandum titled *Consideration of Green and Sustainable Remediation Practices in the Defense Environmental Restoration Program* (DOD 2009), which states that GSR "employs strategies for cleanups that use natural resources and energy efficiency, reduce negative impacts on the environment, minimize or eliminate pollution at its source, protect and benefit the community at large, and reduce waste to the greatest extent possible." Based on EO 13423, the memorandum called for examination of current and future remedial activities from the perspective of preserving natural resources; reductions in energy use and energy efficiency, minimization of emissions, water consumption, materials use, and waste generation; as well as maximizing recycling, reuse, and consideration of remediation technologies with inherent sustainability aspects such as those that using plants that can sequester carbon and/or contaminants and in situ remedies. This memorandum requested that each DOD component evaluate opportunities to implement GSR approaches on remedial action projects and that a briefing on progress on this initiative be provided in June 2010.

3.2.3 Department of the Navy

The Naval Facilities Engineering Command (NAVFAC) is approaching implementation of GSR as part of the Navy's existing optimization program. According to NAVFAC's *Sustainable Environmental Remediation Fact Sheet* (NAVFAC 2009), GSR reviews should be considered during the remedy selection, design, and remedial action optimization phases. These reviews are opportune times to evaluate incorporating GSR practices into the cleanup strategies for Navy sites.

In August 2009, the Department of Navy Optimization Workgroup issued a GSR fact sheet summarizing the need for considering sustainable practices by Navy RPMs and laying out GSR metrics. The fact sheet also discusses methodologies to quantify and reduce the environmental footprints of remedial technologies. The following is the general approach to be used by a Navy RPM to consider GSR, as outlined in the fact sheet:

- determine which sustainability metrics should be considered for the site
- establish and apply a methodology to quantify or characterize each metric
- obtain consensus regarding how metrics are weighed against each other and against traditional criteria in selecting the remedial approach
- identify methods to reduce environmental footprint of remedy components
- prioritize, select, and document what footprint reduction methods should be implemented with consideration of the overall net environmental benefit and available funding

The Navy has developed a list of metrics to consider and evaluate while planning and optimizing remediation projects: energy consumption, GHG emissions, criteria pollutant emissions, water impacts, ecological impacts, resource consumption, worker safety, and community impacts.

In a collaborative effort, Battelle, the Navy, and USACE are developing a GSR tool called SiteWise™. SiteWise is composed of a series of Microsoft Excel spreadsheets that provides a detailed baseline assessment of several quantifiable GSR metrics, including GHGs; energy usage; criteria air pollutants, including SO_x, NO_x, and particulate matter (PM); water usage; and accident risk. SiteWise first divides every remedy into four phases: (1) remedial investigation, (2) remedial action construction, (3) remedial action operations, and (4) long-term monitoring. Each of these phases includes activities undertaken—such as transportation, material production, equipment use, and residual management—that have impacts on the environment. With this structure, the tool is very flexible and can be used to support an evaluation of the environmental footprint of any technology addressed. SiteWise is being improved with useful additions, and the latest version is available on the Navy's Green and Sustainable Remediation Portal.

3.2.4 Department of the Army

The Army Office of the Assistant Chief of Staff for Installation Management (OACSIM) collected GSR examples from the Army components in preparation for the June 2010 briefings scheduled in the DOD memorandum.

The USACE Environmental and Munitions Center of Expertise (EM-CX) has developed a decision framework for incorporating sustainable practices into Army environmental remediation projects throughout the remediation process. This decision framework will be used as interim guidance for USACE and also as the technical basis for any Army-wide guidance that will be developed by OACSIM per the DOD memorandum.

The EM-CX is also piloting, with the Army Environmental Center, the inclusion of sustainability into remedial system evaluation optimization on several Army sites. Two sustainability evaluation tools are being used in these pilots: the Sustainable Remediation Tool (SRT™), developed by the Air Force Center for Engineering and the Environment (AFCEE), and SiteWise, developed by Battelle and jointly purchased by the Army and Navy.

3.2.5 Department of the Air Force

AFCEE is the lead entity within the U.S. Air Force (USAF) and is responsible for developing and promoting green and sustainable practices into the USAF Environmental Restoration Program (ERP). Introducing sustainability metrics into environmental restoration projects is not a new endeavor for USAF. Since the early 1990s, USAF has investigated and promoted inherently sustainable remediation approaches such as monitored natural attenuation (MNA) and enhanced in situ bioremediation (EISB). Additional examples of green and sustainable technologies promoted for USAF environmental restoration sites include phytoremediation, bioslurping, and bioventing. Incorporating technologies such as these into an environmental restoration project can often reduce the environmental impact of the remediation activity. More recently, USAF has begun to take a more holistic approach to evaluating remedial operations and effects in an integrated way. This approach expands on traditional ideas and concepts with a more significant emphasis placed on additional variables including minimization of energy and water use and reuse. USAF also considers social and economic factors that could impact the remedy that is selected and the manner in which it is implemented.

USAF has pursued sustainability in its ERP through such approaches as environmental restoration program optimization, long-term monitoring optimization, groundwater modeling, performance-based environmental management, and remediation risk management. These programs work to include GSR approaches and technologies in remediation selection and design, optimize existing remediation and monitoring systems, and provide a holistic and systematic results-based assessment of restoration programs to expedite site closure. To further encourage GSR, USAF is including requirements in contractual language; regionalizing contracts to optimize monitoring programs; eliminating high-energy engineered remediation systems; drafting guidance for USAF RPMs; providing training, education, and outreach for USAF RPMs and their environmental partners; and partnering with other organizations and federal agencies to facilitate GSR principles being included in USAF ERPs.

In addition to programs and initiatives to encourage the application of GSR principles in the USAF ERP, AFCEE and its partners have developed several tools. One of the tools developed is the SRT, which serves two general purposes: planning for future implementation of remediation technologies at a particular site and providing a means to evaluate optimization of existing remediation systems or to compare remediation approaches based on sustainability metrics. The metrics calculated by the SRT include emissions to the atmosphere (CO_2, NO_x, SO, PM less than 10 µm in aerodynamic diameter [PM_{10}]); total energy consumed; change in resource service; technology cost; and safety/accident risk. All of these metrics can be expressed in "natural" units (e.g., tons of air pollutant emitted), and all but the safety/accident risk can be normalized (monetized) to U.S. dollars to facilitate comparisons using a common denominator.

The SRT is Microsoft Excel-based and free to users. It and a user's guide can be downloaded from www.afcee.af.mil/resources/technologytransfer/programsandinitiatives/sustainableremediation. The SRT enables users to quantitatively evaluate several sustainability metrics for a variety of remediation technologies on a technology module basis. The remedial technologies currently addressed by the SRT are (1) excavation, (2) soil vapor extraction, (3) pump and treat, (4) enhanced in situ biodegradation, (5) thermal treatment of contaminated soil, (6) in situ chemical oxidation, (7) permeable reactive barriers, and (8) MNA/long-term monitoring of contaminated groundwater. These technologies were selected for inclusion in the SRT because they are implemented frequently at USAF environmental restoration sites. Subsequent versions of the SRT will be able to import parameters from the Remedial Action Cost Engineering and Requirements (*RACER*™) cost estimation tool. Training modules and case studies also are under development. The SRT is specifically referenced in AFCEE contracting language, included in the Air National Guard GSR policy, and being used by several agencies as a sustainability baseline for their remediation efforts.

In addition to the SRT, AFCEE developed the Performance Tracking Tool (PTT) that is integral to the AFCEE's promotion of sustainable remediation methods. A free, Microsoft Excel-based tool, the PTT evaluates historic performance of a remedial system (e.g., mass removal) and compares it to expected performance to determine whether the contaminant mass is being reduced at the anticipated rate and whether the operation and maintenance costs are consistent with projections. Knowing this performance information can help the RPM determine whether systems need to optimized, switched to a different treatment approach, or removed from operation. Technologies currently included in the PTT are (1) pump and treat, (2) dual-phase extraction, (3) solvent extraction, (4) soil vapor extraction, (5) bioslurping, and (6) MNA. The PTT can be downloaded from www.afcee.af.mil/resources/restoration/erp-o. The PTT has been applied in several instances, showcasing how results from the tool can lead to more sustainable, efficient, and cost-effective remediation solutions.

In addition to the SRT and the PTT, AFCEE is developing CleanSWEEP (Clean Solar and Wind Energy in Environmental Programs). Again, designed to be free and using Microsoft Excel, CleanSWEEP is a design and decision tool for alternative energy use at remediation sites. The initial version of the tool will focus on all types of remediation systems with power requirements of 1–20 kW. A large subset of groundwater pumping, soil vapor extraction/bioventing, and sparging systems fall within this range of power demand. The tool evaluates the two most commonly available forms of renewable energy (photovoltaic-solar and wind energy systems) and uses existing DOE databases to estimate solar and wind potential. The tool is easily applicable to remote sites. Remediation systems with low energy requirements over long periods as well as those systems which do not require continuous operation can be analyzed using this tool. The tool is simple enough to be used "out-of-the-box" with little training, yet sophisticated enough to make go/no-go and simple design recommendations for small to mid-sized systems. It is also appropriate as a screening tool for large and complex systems. It is designed to be free and available to the public in late 2011 and will complement the application of other GSR tools.

As GSR implementation is becoming prevalent within USAF through the application of tools and approaches as described above, AFCEE is deliberately including GSR language in its contracts, including its performance-based remediation (PBR) contracts. Sustainable practices are required elements in the remedy implementation contracts along with basic elements such as understanding the work and relevant experience. Specific language such as "net positive social and environmental benefit," "incorporate life-cycle sustainability assessment into selection process," "promote new and innovative technologies to conserve natural resources," and "have low energy and low carbon footprint" are often included in the contracts. For PBR contracts, GSR is included as part of the selection criteria, giving those firms who include GSR in their remediation approach an "edge" over those who do not. AFCEE is also seeking innovative solutions that include GSR principles through its Broad Agency Announcement under the AFCEE Technology Transfer Program.

In summary, AFCEE is on the leading edge of GSR development. It is promoting GSR within the USAF ERP through demonstrating and validating GSR technologies, developing GSR and other performance tools for evaluating these technologies, and providing guidance on incorporating GSR language in contracts. This effort is expected to lead to a more sustainable use of resources including, water and energy throughout USAF. It has the potential to expand to other agencies and USAF programs as well as benefit overall USAF installations and local communities.

3.2.6 SERDP/ESTCP

The Strategic Environmental Research and Development Program (SERDP) is DOD's environmental science and technology program. Its role is to fund basic and applied research that addresses environmental issues relevant to DOD's management and mission through a partnership with DOE and EPA. Subsequently, the Environmental Security Technology Certification Program (ESTCP) identifies, demonstrates, and validates innovative environmental technologies that target DOD's most urgent environmental needs and are projected to pay back the investment through cost savings, improved efficiencies, or improved outcomes. The combined goal of these complementary programs is to support the long-term sustainability of DOD's programs by enabling promising technologies to receive regulatory and end-user acceptance and be fielded and commercialized more rapidly. To achieve this goal, ESTCP projects create a partnership between technology developers, responsible DOD organizations, and the regulatory community.

3.2.7 Department of Energy

DOE has considered several initiatives and has championed sustainable approaches for effective remediation of contaminated sites at facilities across the nation. Savannah River National Laboratory (SRNL) recently initiated studies under the DOE's Office of Environmental Management to identify methods for increasing the sustainability of remediation addressing metal- and radionuclide-contaminated groundwater. Sustainable strategies will help meet site-specific cleanup objectives, including long-term risk reduction, while minimizing maintenance, cost, and collateral environmental damage associated with remediation. Current SRNL work focuses on estimating the duration of aggressive remediation strategies before natural processes can be relied on to return the site to precontamination conditions.

3.3 Other Government/Partner Organizations

A number of other organizations are addressing the need to provide research, reference materials, inventories, and integrated expertise with a common goal of environmental industry-wide knowledge and use of green remediation and GSR standards, tools, and information. The work of two such organizations is presented here.

3.3.1 ASTSWMO

Within the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) Sustainability Subcommittee, the Greener Cleanups Task Force has issued the following five strategy papers on green remediation intended to assist state programs in implementing greener cleanups:

- "Implementing Greener Cleanups Strategies in the States," January 2009 (http://astswmo.org/files/resources/greenercleanups/Implementing_Greener_Cleanup_Strategies_in_the_States.pdf)

- "Discussion of Barriers to Greener Cleanups," by Carey Bridges, presented at the April 2009 Mid-Year Meeting in Columbus, Ohio (http://astswmo.org/files/meetings/2009MidYearMtg/Presentations/BRIDGES-Barriers_to_GC.pdf)
- "Incentives for Greener Cleanups," June 2009 (http://astswmo.org/files/resources/greenercleanups/GCTF_Incentives_Paper_6-25-09.pdf)
- "Green Remediation Myth Busters," August 2009 (http://astswmo.org/files/resources/greenercleanups/Green-Remediation-Myth-Busters_August-2009.pdf)
- "Incorporating Greener Cleanups into Remedy Reviews," August 2009 (http://astswmo.org/files/resources/greenercleanups/GCTF_Post_Remedy_Reviews_Aug09.pdf)

These documents are posted on the ASTSWMO Greener Cleanups Information Resources page created by the Task Force: http://astswmo.org/resources_sustainability_greenercleanups.html.

3.3.2 ASTM International

ASTM initiated Subcommittee E50.04 Green Cleanup Task Group in October 2009 to develop a voluntary ASTM standard that may be used widely to assess green cleanups. This effort was initiated in response to a formal request from EPA to ASTM to develop standards for implementing EPA's Green Remediation Principles released in July 2009. ASTM offers value through its unique role for more than 100 years of developing and publishing voluntary consensus standards that have been successfully adopted across numerous industries.

Subcommittee E50.04 comprises members representing federal, regional, and state regulators, industry; environmental consultants; and DOD components, including AFCEE. The working draft title of the ASTM effort is "Standard Guide for Green and Sustainable Site Assessment and Cleanup." The task group has taken the approach of developing a generalized framework that provides flexibility to analyze the environmental, social, and economic aspects, individually or in any combination, of any portion of the contaminated site life cycle under any regulatory regime. Thus, entities that want to strive for greener cleanups will be able to use the environmental aspects of the standard without necessarily implementing the social and economic components. On the other hand, entities desiring to achieve an integrated sustainable cleanup will be free to use the environmental, social, and economic sections of the standard.

The framework embodied in the standard will seek to enhance the corrective action process through holistic considerations of environmental, economic, and social factors while providing for an individual assessment of these factors that can be assembled into a complete sustainability analysis. It is hoped that the guide will provide a consistent, transparent roadmap to a decision-making process for green and sustainable cleanup actions. The goal of the standard is to outline a decision-making process that will allow site stakeholders to maximize the short- and long-term goals under various cleanup programs while continuing to protect human health and the environment.

The remainder of the draft standard document will be composed of the following three sections:

- planning, scoping, and screening
- core elements
- a two-tiered decision-making process and strategy for green and sustainable tracks

It is anticipated that the last section will have a decision matrix with three categories consisting of the three sustainability elements (environmental, social, and economic), versus three tiers of information collection and complexity (low, medium, and high). The subcommittee's work continues to move forward via subgroups assigned to the various sections of the standard. At this writing, draft versions of the various chapters are being developed, circulated, and edited among the members of the work group. After the draft has been completed, it will be submitted to ballots at the subcommittee, committee, and society levels in accordance with ASTM protocols. If any negative ballots are returned at any of these levels, the task group will convene to address the objections and comments received. ASTM will issue the standard after the document has successfully completed balloting at all three levels.

3.4 Private Sector and International Organizations

It is important to recognize that, while defining and achieving green remediation is currently the focus of governmental agencies, responsible parties, manufacturers, and industry have forged ahead with the conceptualization of a GSR approach that balances environmental considerations and protection of health and the environment with economic and social considerations to optimize a remediation.

3.4.1 SURF (U.S.)

The Sustainable Remediation Forum was initiated in late 2006 to promote the use of sustainable practices during the entire remediation process. About 20 individuals from different sectors of the remediation industry attended the first meeting of SURF, which now has over 200 members from consulting, industry, government, and academia. It has held more than 10 meetings at locations across the United States and has inspired the creation of other sustainable remediation organizations around the world. The SURF white paper (Hadley and Ellis 2009), published in *Remediation Journal* in summer 2009, 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. Major sections in the SURF document include description and current status of sustainable remediation; sustainability concepts and practices in remediation; impediments and barriers; a vision for sustainability; application of sustainable principles, practices, and metrics to remediation practices; and conclusions and recommendations. SURF defines sustainable remediation broadly 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."

SURF members believe that a balance between sustainability and other criteria should be, and will be, maintained. Looking at the selection of remediation alternatives through a sustainability framework is an inclusive method to consider all on-site, off-site, and global impacts in decision making so that decisions on trade-offs are made in a deliberate, informed, and thoughtful manner. SURF incorporated as a New Jersey nonprofit corporation for scientific and educational purposes in 2010. The membership voted on incorporation, decided on the membership structure, and elected officers in January 2010. More information about SURF's activities can be obtained at SURF's website, www.sustainableremediation.org.

3.4.2 SuRF-UK

SuRF-UK is the United Kingdom's Sustainable Remediation Forum. Following its U.S. counterpart, SuRF-UK's primary initiative is to further the understanding of sustainable remediation in the UK. Trying to understand the key indicators associated with the sustainable remediation process is an important goal of the SuRF-UK. Members are developing a framework to embed balanced decision making in the selection of remediation strategies to address land contamination as an integral part of sustainable development.

3.4.3 Network for Industrially Contaminated Land in Europe (NICOLE)

NICOLE is considered one of the leading forums on contaminated land management in Europe, including an estimated 361 members. NICOLE promotes cooperation between industry, academia, and service providers on the development and application of sustainable technologies. NICOLE also provides a European forum for the dissemination and exchange of knowledge and ideas about contaminated land arising from industrial and commercial activities.

NICOLE created a Sustainable Remediation Workgroup, and the top issue is the need to engage agencies, problem owners, communities, and other stakeholders in the remedial process. The organization also has identified that success can best be achieved by adopting a bottom-up approach, using the example of working with regulatory agencies on a site-by-site basis, instead of setting policies and wide-ranging definitions. To help with this bottom-up approach, it built a "Road Map for Sustainable Remediation" that was published in September 2010 and presented at the ConSoil 2010 Conference in Salzburg. This roadmap presents the principles and methodology developed by NICOLE to implement sustainable remediation on any kind of project. In association with this roadmap, it is finalizing a few technical chapters as support documents and is in the process of developing a "Road Map for Sustainable Remediation Pilot Test" asking NICOLE members to test the roadmap on real cases. Results on this test process are expected in early 2012, following which it will be available to the larger community of practitioners.

4. METRICS

Metrics applicable to GSR can address the environmental, social, and economic aspects of a project and can help move a remediation project from merely green to sustainable. Currently, there is no commonly accepted set of metrics used by remediation practitioners to evaluate whether site cleanup activities are green and/or sustainable. However, multiple publications and organizations have begun discussing, introducing, and evaluating the need for such metrics (e.g., SURF paper, SuRF UK paper, ASTSWMO, NAVFAC).

The SURF white paper published the most complete compilation of sustainable remediation metrics available to date, referred to in the document as the "Sustainable Remediation Framework." These metrics are presented in Table 4-1 with minor changes to some of the metric names. Many of these metrics were drawn from concepts and ideas proposed in EPA's green remediation primer (EPA 2008a). As presented in the SURF white paper, these metrics were flagged for applicability (mapping) to each of the three elements of the sustainability "triple bottom line"—environmental, social, and economic. Some of the metrics in Table 4-1 can be mapped to more than one triple bottom line element. The metrics provided in the SURF white paper were expanded in Table 4-1 to propose units of measure for each metric (if applicable) as well as a description of the metric.

Table 4-1. Green and sustainable remediation metrics

Sustainable remediation practices and objectives	Land	Water	Waste	Community	Economic	Metric units	Metric description
Fresh-water consumption						Gallons	Volume of fresh water used
Water reuse						Gallons, percentage	Volume of water used, percentage of water reused
Groundwater protection						Gallons, acre-feet	Volume of groundwater protected
Surface water protection						Gallons, acre-feet	Volume of surface water protected
Bioavailability of contaminants						Kg	Mass of bioavailable contaminants
Biodiversity						Specie count	Assessment of impacts on biodiversity
Habitat disturbance						Ecosystem services, area of land impacted	Measure of impact on area impacted or change in ecosystem services
Ecosystem protection						Ecosystem services, area of land impacted	Measure of impact on area impacted or change in ecosystem services
Natural resource protection						Acres, acre-feet, ecosystem services, human use value	Measure of impact on natural resources or natural resources quality
Nonrenewable energy use						Gallons, BTU, kWh	Measure of use of nonrenewable energy resources
Renewable energy use						Gallons, BTU, kWh	Measure of use of renewable energy
Net energy reduction						Percentage	Percent change from baseline
Greenhouse gas emissions						CO_2 equivalents emitted	Tons of GHGs emitted
Air pollution (non-GHGs)						Pounds emitted	Pounds of air pollutants emitted

Sustainable remediation practices and objectives	Land	Water	Waste	Community	Economic	Metric units	Metric description
Contaminant migration						Mass migration over distance, flux	Measure of amount of mass migrated over distance and time. flux is a measure of mass migration through an area cross-sectional and perpendicular to flow
Material use						kg	kg of total material use, or mass by category of material
Material extraction						Mass per mass	Mass of material extracted per mass recovered
Waste reduction						Volume or mass diverted	Measure of water diverted from landfill or wastewater treatment operations
Reuse of materials						Volume or mass reused	Measure of water diverted from landfill; could also use $ for savings aspect or reuse, volume of water reused
Life-cycle cost						$	Costs associated with complete life cycle
Use of recycled materials						Mass or percentage of materials reused	Mass or volume of material reused in proportion to virgin materials
Net environmental benefit						Discounted service acre years, human use value	Measure of impact (negative or positive) to ecosystems and human use
Consider cost of the “sustainability delta,” if any						$ per improvement from implemented sustainability	Normalize impacts of sustainability to a common unit and factor in cost
Property value						$ or subjective	Improvement in property value as a result of implementing remedy
Tax base						$	Improvement in taxable value of property
Employment						Jobs created	Number of jobs created as a result of implementing remedy
Capital costs						$	Capital costs of project
Operations and maintenance (O&M) costs						Present value of O&M costs ($)	Present value of O&M for project life cycle
Worker risks						Fatality and injury	Potential for fatality or injury based on worker-hours and miles driven
Community risks						Fatality and injury	Potential for fatality or injury based on miles associated with off-site transportation
Land reuse						Acres	Acres of land reused for beneficial reuse
Local material use						Percentage of material for local sources	Percentage of materials procured for project from local sources
Noise						dB	Noise level of project
Odor						Subjective	Olfactory impacts of project
Lighting						Lumens	Increase of lighting intensity to nearby impacted people
Environmental justice						Subjective	Potential for project to disproportionately disadvantage communities
Community impacts						Subjective	Impacts of project on the community

Sustainable remediation practices and objectives	Land	Water	Waste	Community	Economic	Metric units	Metric description
Cultural resources						Subjective	Impacts of project on cultural resources
Stakeholder involvement						Subjective	Involvement of interested stakeholders in project decisions
Access to open spaces						Subjective	Impacts of project on public access
Maximize future land-use potential						Acres	Maximize future land use of property for uses that are beneficial to the local community

One challenging element of sustainability, in terms of applying metrics, is the lack of available metrics that evaluate social impacts. In Table 4-1, several of the social metrics can be evaluated only qualitatively, which can make the determination of social impacts difficult. More research into applying social metrics to GSR is needed to obtain a better understanding of the social impacts of site cleanup and to use these metrics with any measure of certainty about their accuracy and magnitude of impact.

SuRF-UK also evaluated the application of current/available sustainability indicators to remediation. *A Review of Published Sustainability Indicator Sets*, published by SuRF-UK, lists additional metrics and how they could be accounted in sustainability analysis. For each element of sustainability (environmental, social, and economical), the paper evaluated metrics for six indicator categories. SuRF-UK evaluated over 2,400 indicators and found that more work is needed to apply the available indicators to remediation.

The list of metrics in Table 4-1 should not be considered all-encompassing, and some metrics are difficult to quantify. Each project may identify unique metrics that may not be represented in Table 4-1. However, for the purposes of conducting GSR evaluation, this list is considered reasonably complete and created from reputable sources and thus serves as a good baseline. In many cases, a GSR evaluation will likely use a smaller number of metrics than those listed in the table. It is important to note that there is currently division over the applicability of the worker safety and community impacts metrics because some practitioners believe that these metrics are already accounted for in the remedy selection process.

Other entities have also developed metrics. NAVFAC issued a fact sheet (NAVFAC 2009) that lists eight metrics relevant for GSR at the Navy's cleanup sites: energy consumption, GHG emissions, criteria pollutant emissions, water impacts, ecological impacts, resources consumption, worker safety, and community impacts. The NAVFAC fact sheet provides brief discussion about each of these metrics. The SiteWise tool developed by Battelle evaluates five quantifiable metrics (energy consumption, GHG emissions, criteria pollutant emissions, water impacts, and worker safety) for GSR evaluation. In addition, the AFCEE SRT evaluates the following five metrics: GHG emissions, energy consumed, technology cost, safety/accident risk, and natural resources services. EPA Region 9 used five environmental metrics, and no social or economic metrics, in assessing the footprint of remedial technologies at the Romic East site in

Palo Alto, California (EPA 2009b): material and fuel usage, waste generation, water consumption, electricity usage, and CO_2 emissions, omitting the metrics associated with safety/ accident risk.

More work will be done by the ITRC GSR Team to formulate metrics and discuss these in detail in its forthcoming technical and regulatory guidance document.

5. GSR RESOURCES, METHODS, AND TOOLS

As the implementation of GSR becomes more prevalent in the remedial process, more information is becoming available regarding the manner in which the benefits of GSR can be assessed and evaluated. A variety of resources are available to assist in the overall assessment of the environmental footprint of remedial activities and GSR benefits. This section provides an overview of the various methods and tools that are currently being used or are under development to promote more green and sustainable practices during remediation.

5.1 Resources

There are several resources and tools available for applying GSR approaches at a variety of site-specific conditions. For example, many agencies and regulatory programs and initiatives actively support site remediation and revitalization that result in beneficial reuse such as commercial operations, industrial facilities, housing, greenspace, and renewable energy development. EPA, DOD, DOE, and state agencies are developing resources to support GSR approaches and processes that are specific to their respective use and benefit, as well as for the benefit of general public. These agencies have begun examining opportunities to integrate sustainable practices into the decision-making processes and implementation strategies that carry forward to reuse strategies, disseminating a wide variety of information regarding GSR tools. EPA's OSRTI and OSWER are working with private and public partners to foster the use of BMPs for green remediation at contaminated sites throughout the United States by documenting the state of BMPs, identifying opportunities for improvement, establishing a community of BMP practitioners, and developing mechanisms and tools to help site cleanup and reuse stakeholders make informed decisions about green cleanup strategies.

As discussed in Section 3 of this document, EPA has prepared a technology primer entitled *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* (EPA 2008a), which provides information on the principles of green remediation and a variety of resources to assist in the application of green remediation to remedial sites. Section 5.0 of the green remediation primer, entitled "Tools and Incentives," lists resources that can help practitioners incorporate such elements as green power and energy efficiency into the site management process. EPA also published *Superfund Green Remediation Strategy* (EPA 2010c) in September 2010.

5.2 Methods

Two general methods to approaching the evaluation of GSR impacts and benefits with a broad scope are life-cycle assessment (LCA) and net environmental benefits analysis (NEBA). This section provides information about these two methods. As GSR evolves and matures, it is likely that additional approaches will become available.

5.2.1 Life-Cycle Assessment

The International Organization for Standards (ISO) developed a standard for LCA, which it defines as the "compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle." It should be noted that the ISO definition of "product" also includes "services" and therefore includes remediation projects. The international standard goes on to clarify that LCA is "one of several environmental management techniques (e.g., risk assessment, environmental performance evaluation, environmental auditing, and environmental impact assessment) and might not be the most appropriate technique to use in all situations. LCA typically does not address the economic or social aspects of a product, but the life-cycle approach and methodologies described in this international standard can be applied to these other aspects." This document uses the ISO definition of LCA and emphasizes further the social and economic impacts of the LCA process.

LCA provides a method for evaluating the total effects a product has on the environment over its entire existence, starting with its production and continuing through its eventual disposal. Applying LCA to a service such as a remedial activity similarly tracks the effects of production, transportation, use, and disposal of different materials and products associated with that activity. LCA accounts for energy and resource inputs as well as polluting outputs to land, water, and air.

LCA is a promising approach to evaluating, selecting, and improving remediation systems in a GSR analysis. LCA can take into account both direct and indirect impacts during all phases of remediation, including site characterization, remedy implementation, system operation and monitoring, and land end use. Methods for identifying and characterizing GSR metrics range from qualitative approaches to very detailed quantitative efforts. Thus, LCA can be used to identify the best approach for minimizing the consumption of natural resources (minerals, water, land, fossil fuels), generation of solid and liquid wastes, air pollutants (including GHG), cost (net present value), and time (simple payback period), while maximizing reuse of natural resources, renewable energy sources, useful land end use, and habitat and ecosystem restoration.

In general, the framework for LCA involves the following steps:

1. Define goals, scope, and key assumptions.
2. Conduct an inventory analysis (constructing a process flow chart, defining the system boundaries, and collecting and processing data).
3. Assess overall impact (classification, characterization, and valuation of impacts).
4. Interpret and assess potential for improvement (reporting and assessing ways to reduce the product's or activity's footprint).

The practical implementation of LCA requires consideration and selection of boundary conditions, aspects that can be excluded as they result in minimal impacts, metrics and measurement methods, and tools to support the analysis. With respect to boundary conditions, the most rigorous approach is to consider full cradle-to-grave analysis for all materials used from the mining of raw materials to the ultimate disposal or reuse of residuals. A less rigorous approach could go back to the manufacturing step of the products consumed but would not consider the impacts of getting the materials to the manufacturer. An even less rigorous approach might consider only the impacts that occur on the site. The LCA process is flexible and can be simplified based on the specific application with limited scope, simplified assumptions, and defined assessment boundaries. Thus, LCA can be used for everything from "rough estimates" to very detailed assessments. Care must be taken not to shortcut the LCA by failing to take the analysis far enough back into the manufacturing to avoid undercounting of key parameters.

Some of the deterrents against using LCA for GSR analyses include the perception of lack of readily available input data, the significant time requirement associated with the analysis, lack of training on LCA for environmental remediation professionals, and interdisciplinary collaboration required to comprehensively assess sustainability issues. In addition, there are currently few if any readily available applications to allow LCA to be used during the evaluation of various GSR approaches under consideration at a contaminated site. There are, however, a variety of standard LCA tools with databases that can be used, which are generally no more complicated than other conventional tools and models used in the remediation industry. When conducting an LCA, the data collection phase is typically the most time-intensive portion of the schedule and needs to be completed regardless of which impact-estimating tool is being used. Multidisciplinary participation and coordination are required regardless of the impact tool used.

5.2.2 Net Environmental Benefits Analysis

NEBA is another method that can be used to incorporate green and sustainable concepts into remediation. This approach allows a systematic evaluation of changes in natural resource values (ecological and human uses) associated with different land management alternatives (including those employed during remediation). Consistent comparisons across alternatives can be conducted to identify the optimal option that achieves the greatest environmental benefit and also has the lowest overall socioeconomic impact, or conversely provides the best socioeconomic outcome. The NEBA method identifies and values the primary environmental services that an area or portfolio of holdings may provide given different land uses and actions (e.g., managing wildlife, discharging effluent, or restoring habitats). The type, quantity, and quality of environmental services provided by an area or waterway are determined, in part, by the surrounding geographic landscape. Proposed actions may affect the quality and quantity of ecological and human use services produced at the site or parcel differently. Some services may be improved, some may not be affected, and some may be harmed.

The NEBA method can be used to accomplish the following:

- estimate the value of environmentally sensitive areas
- develop and evaluate a suite of alternatives
- provide a basis for balancing economic, human, and natural resource drivers affecting proposed alternatives
- support measures to weigh and rank alternatives that meet cost-effective objectives
- provide a means to expand the range of potentially acceptable alternatives
- provide documentation that provides a defensible alternative analysis and selection
- provide a basis for establishing appropriate mitigation measures

- provide performance-based measures that can be used to conduct monitoring and adaptive management activities

When properly planned and implemented, the NEBA approach provides a systematic, consistent, and defensible process that can significantly enhance stakeholder support for selected environmental and land use planning decisions.

The NEBA process can be configured in the following manner as it applies to GSR:

- identify response actions or remedial alternatives
- generate conceptual site model (CSM), including likely receptor populations, exposure pathways or "stressors," and other resources of concern
- determine the potential impact (positive and negative) of each remedial alternative on the receptors and/or resources in relation to ecological value and human use
- develop a risk ranking matrix to evaluate or score the potential impact for each remedial alternative
- complete and document a relative risk summary for each scenario to aid in decision making

NEBA is currently used by EPA and others to evaluate oil spill response strategies as part of contingency planning.

5.3 Tools

Several tools are available to implement the above methods, and more are being developed. A set of automated and semiautomated tools applicable to the remediation decision-making process is available or currently under development to help evaluate the environmental actions and impacts which may be caused by remediation activities and also to consider the social and economic aspects. Some example tools, such as SiteWise and SRT, have already been mentioned in this document. Many regulators and responsible parties, ranging from the chemical industry to DOD, employ these tools to analyze sustainability factors when selecting new remediation systems and for evaluating and optimizing existing systems. Such tools range in complexity and scope from a list of factors to consider qualitatively to software platforms that enable quantitative, site-specific estimates. Some tools attempt to be comprehensive by considering a variety of environmental, social, and economic factors, as well as impacts and costs from a life-cycle approach. Other tools seek to address specific impacts (for example, GHG emissions) and may not look for impacts beyond a particular spatial or temporal boundary. Appendix A provides a list of tools. Though this is not an exhaustive list of all available tools, many freely available, as well as proprietary tools, are discussed. As the GSR process develops, many more tools are expected to be developed, and the ITRC GSR Team will maintain the list on its website at www.itrcweb.org.

5.3.1 Office of Superfund Remediation and Technology Innovation Matrix of Tools

At www.clu-in.org/greenremediation/subtab_b3.cfm, EPA's Contaminated Site Clean-Up Information (CLU-IN) website provides a matrix of GSR tools based on a dataset compiled by OSRTI, last updated in May 2009. Appendix A provides key tools from the CLU-IN matrix, in addition to a variety of additional tools available to assist in the evaluation of GSR. Most of the tools listed are useful in assessing environmental factors and providing information on how to "green up" a remediation, but only a few provide insight into the social and economic aspects that can be considered and balanced with the environmental considerations to result in a more sustainable remediation. A number of tools are currently employed by the remediation industry to evaluate the green remediation component of GSR, and other tools include broader gauges of sustainability. Some of the tools identified are directly applicable to remediation technologies, while others consider the impacts of raw materials used during remediation. While every effort has been made to provide comprehensive, up-to-date information on the state of green and sustainable tool development, the examples provided are not exhaustive.

5.3.2 Risk-Screening Environmental Indicators

EPA's Risk-Screening Environmental Indicators (RSEI) tool is used to evaluate the risks associated with a site remediation project. RSEI is EPA's computer-based screening tool for the evaluation of toxic chemical releases and transfers from industrial facilities. EPA created RSEI in response to a growing need to track changes in human health risks and to facilitate strategic planning and priority setting for long-term reduction of health impacts. Various government agencies and private industries are using RSEI for performance tracking and risk ranking. RSEI is not listed in the EPA OSRTI table for Green Remediation: Footprint Assessment Tools.

RSEI assesses factors related to potential chronic human health risks from industrial pollution and waste management and assigns a score, which can added and compared to other RSEI scores to assess the relative risk. The scores are for comparative purposes and are meaningful only when compared to other scores produced by RSEI. It is designed to investigate a wide variety of industry sectors, analyze trends, and assess impacts of cross-media risk transfers. Since remediation activities can result in media transfer of contaminants, as well as contaminant transformations, RSEI may be well suited to waste site cleanup activities. RSEI can help identify opportunities with the greatest potential for hazard or risk reduction. RSEI does not evaluate ecological effects of releases.

The RSEI model uses annual reporting from individual industrial facilities along with a variety of other information to evaluate chemical emissions and other waste management activities. RSEI incorporates detailed data from EPA's Toxics Release Inventory, the Integrated Risk Information System, the U.S. Census Bureau, and other sources. Using existing EPA models, RSEI incorporates the full spectrum of risk-related factors by considering the following:

- amounts of toxic chemicals that facilities release
- environmental concentrations attributable to these releases
- doses that people receive from these environmental concentrations
- relative long-term toxicity of these doses
- number of people who are affected

RSEI can be used to perform efficient screening-level activities to target the greatest potential for risk reduction. It does not serve as a detailed or quantitative risk assessment, but it can compare many risk-related chronic human health problems associated with releases of toxic chemicals. Tracking changes in risk-related results could measure progress in environmental protection associated with remediation as well as pollution prevention programs. Since RSEI is a screening tool and not a qualitative risk assessment, the model should be supplemented with more focused analysis when more detail is required.

6. INTEGRATION AND IMPLEMENTATION

The integration and implementation of GSR practices into the site remediation process requires an understanding of the following key elements:

- applicable programs and requirements given the location of the project site (An increasing number of states and other organizations have GSR guidance or programs that identify how to integrate GSR concepts.)
- metrics that best fit the particular project given the GSR activities being considered
- tools that enable a user to evaluate the applicability and benefits resulting from a particular GSR practice, considering the environmental, social, and economic aspects
- options available to "link" a GSR activity with a program that provides financial incentives resulting from such activities as the use of renewable energy, energy conservation measures, or the creation of open space or protected habitats.

The consideration of GSR throughout the site remediation process requires a balanced decision-making process in which all reasonable GSR options are considered and the net benefits are defined in the context of the environmental, social, and economic aspects of the project. It should be noted that not many sites have all these three aspects well defined in an equal proportion. For example, at a majority of sites, developing social aspects are much more difficult than developing environmental aspects and economic aspects. In such cases social aspects (and in some cases economic aspects as well) need to be addressed where, and to the extent, possible.

GSR options such as the following examples should be considered throughout the site remediation process during the planning of each of the primary phases:

- site investigation
- feasibility study/response action plan
- remedial design
- remedial action implementation/construction
- remedial action O&M
- remedial process optimization
- site closure

Table 6-1 presents a set of example GSR elements to be considered during each phase of remediation process and suggests how these element could apply to addressing the environmental, social and economic aspects of the remediation. This list is certainly not exhaustive, and the examples provided are a good starting points for most RPMs who should develop site-specific elements that are most appropriate to their cases as appropriate.

Table 6-1. Example GSR considerations during remediation phases

Process step	Environmental	Social	Economic
Site Investigation	• Collect data to address on-site and in situ management and treatment options • Collect data to understand risks associated with on-site treatment and containment of contaminated media • Identify and minimize generation of sampling waste minimization measures • Identify recycling options for materials generated during site investigation • Identify methods (e.g., drilling, land disturbance) that minimize impacts to ecosystem • Develop/enhance CSM	• Conduct community outreach/notifications to communicate site conditions and risks and to engage in planning of site cleanup and reuse options • Create key contacts list to facilitate communications/ notifications • Engage key internal and external stakeholders	• Use field screening technologies to reduce off-site sample shipping costs • Begin to examine relative costs of possible remedies
Feasibility Study/ Response Action Plan	• Evaluate on-site and in situ treatment and containment technologies • Conduct energy use and emissions calculations to compare alternatives • Identify opportunities to create habitat as part of site remediation • Consider emerging technologies with lower impact • Reexamine and update CSM • Develop exit strategies for ultimate disposition of site	• Communicate site remediation options and risk reduction achieved to stakeholders • Obtain input on site cleanup alternatives and community concerns/ needs • Obtain other stakeholder input/concerns	• Determine short- and long-term cost of site remediation alternatives • Assess and compare social costs/benefits • Evaluate options to provide green space • Evaluate options to restore properties for reuse • Evaluate opportunities for energy generation potential (Re-Powering America)

Process step	Environmental	Social	Economic
Remedial Design	• Identify low-energy, low-emission, and low-water-intensive technologies and equipment • Minimize impacts to local natural resources and habitats • Maximize use of renewable energy and fuels • Minimize off-site transport of contaminated materials • Identify recycling options for materials addressed during site remediation • Use on-site treatment and containment approaches • Design remote monitoring features into long treatment systems • Ensure CSM is still representative • Use value engineering and optimization techniques to maximize design effectiveness • Design O&M to minimize life-cycle waste generation	• Engage community leaders in design meetings to obtain input on configurations and timing of site work • Communicate with or notify stakeholders of site remediation plan, including short-term community impacts and long-term risk reduction • Obtain input on community concerns/ needs • Continue to involve other stakeholders	• Use on-site approaches to management of contamination to reduce costs of site cleanup and potential long-term liabilities associated with off-site disposal • Use adaptive site-reuse approach incorporating existing buildings into site reuse options • Design O&M systems to minimize life-cycle costs
Remedial Action Implementation/ Construction Management	• Minimize equipment engine idling • Control and mitigate dust, odors, noise, and light impacts • Conduct monitoring of air and, if needed, odors, noise, and light • Set up comprehensive on-site recycling program for all wastes and residuals • Reexamine and update CSM	• Implement community notifications and/or conduct community meetings to inform of project progress • Post information on monitoring programs and project progress/plans • Maximize use of local businesses for goods and services	• Consider benefits to the society in terms of economic benefits, not just cost savings for the principal responsible party in the execution of the GSR
Operations, Monitoring and Maintenance	• Use remote monitoring system to monitor effectiveness of treatment systems and reduce field travel • Recycle sampling residuals • Identify waste minimization measures • Reexamine CSM	• Communicate site remediation status using website and other public communication approaches, including mailings/other notifications • Maximize use of local businesses for goods and services	• Use low-energy-intensive approaches to reduce energy costs • Use on-site sample testing/screening approaches to reduce shipping/laboratory analytical costs • File electronic reports to reduce shipping costs

Process step	Environmental	Social	Economic
Remedial Action Optimization	• Maximize efficiency • Optimization of existing systems to reduce carbon footprint, energy, and overall environmental impact of resource consumption • Identify alternative methods or technologies that are equally protective but use less energy and resources • Reexamine and update CSM	• Communicate with or notify stakeholders of remedial program efficiency in measurable terms (e.g., mass removed per dollar) • Communicate with or notify stakeholders of optimization of remediation systems and reduced impacts on energy use and GHG production to achieve a net positive environmental impact	• Maximize efficiency of systems to reduce energy, maintenance costs, and overall operational timeframe • Optimization may reduce treatment costs and allow funding to be used to promote green and sustainable solutions such as alternate energy conversions
Site Closure	• Ensure protectiveness of remedy • Confirm ongoing CSM • Implement exit strategies	• Maintain communications with stakeholders • Identify land use and redevelopment opportunities	• Monitor land use activities and opportunities

The implementation of GSR approaches in remedy closure decisions may become very important as the indefinite continuation of energy-intensive treatment systems or other treatment operations that are approaching diminishing returns with respect to decreasing contamination become more difficult to justify. The examination of impacts from prolonged continued operations with minimum environmental benefit may lead to adoption of alternative cleanup end points (ITRC 2011). For CERCLA sites, anticipated successive changes to the selected remedial action, such as moving from active to passive remediation, must be documented in the record of decision to be implemented.

The forthcoming ITRC GSR technical and regulatory guidance document will provide details on how to properly consider the broad array of issues introduced in Table 6-1. For practitioners in the process of considering GSR and how to accommodate its concepts in ongoing site remediation projects, Section 5 of this document identifies readily available reference materials to enable GSR concepts to be evaluated and applied on projects.

While GSR is described as a process or defined in the context of comparing alternatives, there are a number of factors that contribute to the sustainability of a particular remedy. Some remediation approaches and technologies are inherently less energy-intensive than other more traditional methods. For example, with respect to site characterization, passive sampling that does not involve extensive mobilization may be preferable as long as the method can accurately assess the risk of the site. Phytoremediation, engineered wetlands, biowalls, in situ treatment, and MNA, if effective, may be less costly to the overall site life-cycle cost than thermal, pump-and-treat, or excavation approaches. The use of renewable energy, such as wind turbines and solar photovoltaic for electricity production is widely considered desirable from the sustainability perspective; however, in some cases short-term and aggressive remediation methods may provide a greater removal of contaminants and produce lower GHG and other air emission impacts than a long-term and less effective in situ treatment technology. For example, excavation and landfill disposal of contaminated soil may produce a smaller carbon footprint than several years of soil vapor extraction. The full life-cycle impacts of remedies must be evaluated before ranking them on a "green and sustainable" scale.

Another aspect of GSR is that traditional remediation methods currently in place can be made considerably greener through adoption of technologies that improve the operations. For example, moving large amounts of contaminated soils or transporting materials as part of remediation activities can at times be unavoidable, involving the prolonged use of diesel equipment. Under these circumstances modifying operations, using alternative fuels, or retrofitting engines with emission control devices and instituting idling restrictions can all be used to reduce emissions. Similarly, pump-and-treat operations can be made more efficient through performing of energy audits; installing high-efficiency lighting, pumps and motors, variable-frequency drives; and making use of demand response programs. Adoption of BMPs for such remedies allows for quick implementation.

There are also innovative alternatives that have not been widely explored in context of green remediation, such as heat integration through the use of combined heat and power systems and solar thermal systems, geothermal heating of pump-and-treat buildings, and the use of wind power for mechanical pumping and inline microturbines to cogenerate energy during pumping operations. Likewise a less examined factor in GSR is the choices of materials and treatment chemicals. Much of the GHG emissions and waste production associated with remediation may be related to off-site rather than on-site activities. GHG emissions associated with off-site activated-carbon production or regeneration can be equivalent in scale to those associated with on-site electricity use. Also, the toxics and waste generation from polyvinyl chloride production can be greater than a functionally acceptable alternative to this material. Examination and comparison of acceptable alternatives for materials and treatment chemicals and serious consideration of equivalent materials made from biobased rather than petroleum feedstocks could become an integral part of GSR.

The main point is that an analysis of alternatives should examine the entire cost of producing the materials used and discarded during remediation to truly reduce the footprint of the remediation. As these calculation methodologies are still in their infancy, a rigorous assessment is important.

7. EDUCATION AND TRAINING

The incorporation of GSR principles and practices has evolved over time, coinciding with the growth and maturation of the remediation industry as a whole. Like any other evolving process, education and training for proper understanding and implementation are very important. The ITRC GSR Team recognizes this need and will offer training on the forthcoming technical and regulatory guidance document. The ITRC GSR Team is well situated to take advantage of many other GSR-related programs and projects that are evolving as the technical and regulatory guidance document is being prepared. Using the resources and network available with the ITRC organization, Internet-based training will be developed to meet the needs of the regulatory and regulated community in the areas of GSR.

The GSR Team Communications Subgroup identified particular areas of interest in education and outreach tools, including but not limited to typical ITRC Web-based training specifically due to its inherent green benefits, brochures, fact sheets, and how-to reference publications. Use of the Internet and communication tools will be explored and put to the maximum use.

Early, frequent, and continuous education and communication with legislative bodies was identified by the Communications Subgroup as an additional area of focus. This component was recognized for its high impact potential on GSR development in the United States.

In addition to ITRC resources, EPA's CLU-IN and AFCEE's Air Force Restoration Technology Transfer workshops, short courses at Battelle, and Association for Environmental Health and Sciences conferences are all excellent opportunities for training and education.

8. REFERENCES

AFCEE (Air Force Center for Engineering and the Environment). 2004. *Air Force Guide to Sustainable Operations*.

CLIOS Process Group. 2007. The *CLIOS Process: A User's Guide*. Cambridge, Mass.: Massachusetts Institute of Technology.

DOD (U.S. Department of Defense). 2009. *Consideration of Green and Sustainable Remediation Practices in the Defense Environmental Restoration Program*. Office of the Under Secretary of Defense.

DTSC (California Department of Toxic Substances Control). 2007. "Green Remediation." www.dtsc.ca.gov/OMF/Grn_Remediation.cfm.

EPA (U.S. Environmental Protection Agency). 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA.*

EPA. 2008a. *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites*. Office of Solid Waste and Emergency Response. www.clu-in.org/download/remed/Green-Remediation-Primer.pdf.

EPA. 2008b. *Incorporating Sustainable Practices into Site Remediation*. Office of Solid Waste and Emergency Response fact sheet.

EPA. 2009b. "Use of SRT at Romic Site," Office of Research and Development, Superfund and Technology Liaison, Region 9 Newsletter 49.

EPA. 2010a. "Basic Information: What Is Sustainability?" www.epa.gov/sustainability/basicinfo.htm.

EPA. 2010b. "Green Remediation." www.clu-in.org/greenremediation.

EPA. 2010c. *Superfund Green Remediation Strategy*. Office of Solid Waste and Emergency Response, Office of Superfund Remediation and Technology Innovation. www.epa.gov/superfund/greenremediation/sf-gr-strategy.pdf.

Executive Order 13423. 2007. *Strengthening Federal Environmental, Energy, and Transportation Management*.

Executive Order 13514. 2009. *Federal Leadership in Environmental, Energy, and Economic Performance*.

Galisteo Consulting Group. 2004. *Assessing Social Impacts in the Superfund Process*. Prepared for the U.S. Environmental Protection Agency Office of Superfund Remediation Technology Innovation (OSRTI) under contract PO2W3711TASA.

Hadley, P., and P. D. Ellis, eds. 2009. "Sustainable Remediation Forum [SURF] White Paper—Integrating Sustainable Principles, Practices, and Metrics into Remediation Projects," *Remediation Journal* **19**(3): 5–114.

ITRC (Interstate Technology & Regulatory Council). 2011. *Project Risk Management for Site Remediation*. RRM-1. Washington, D.C.: Interstate Technology & Regulatory Council, Remediation Risk Management Team. www.itrcweb.org.

NAVFAC (Naval Facilities Engineering Command). 2009. *Sustainable Environmental Remediation Fact Sheet.*

SuRF-UK (Sustainable Remediation Forum–UK). 2009. *A Framework for Assessing the Sustainability of Soil and Groundwater Remediation.*

U.S. Army. 2004. *Army Strategy for the Environment*.

Vilsack, R. 2009. "Green Workforce Needs of Minnesota Businesses," in *Minnesota Employment Review*, Minnesota Department of Employment and Economic Development. www.positivelyminnesota.com/Data_Publications/Employment_Review_Magazine/June_2009_Edition/Green_Workforce_Needs_of_Minnesota_Businesses.aspx.

World Commission on Environment and Development. 1987. *Report of the World Commission on Environment and Development*. United Nations General Assembly Resolution 42/187.

Certification Standards References

American Carbon Registry: www.americancarbonregistry.org/carbon-registry/projects

Chicago Climate Exchange: http://theccx.com

Climate Action Registry: www.climateregistry.org/tools/protocols.html

Climate Action Reserve: www.climateactionreserve.org

Climate, Community, and Biodiversity Alliance, for forestry/agricultural projects: www.climate-standards.org

Environmental Resources Trust, now part of Winrock International: www.winrock.org/feature_ert_200802.asp

Regional Greenhouse Gas Initiative: http://rggi.org

Voluntary Carbon Standard: www.v-c-s.org

Appendix A

Tools Designed for Site Remediation

TOOLS DESIGNED FOR SITE REMEDIATION

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Free to Public													
ATHENA® Impact Estimator for Buildings and ATHENA® Eco Calculator for Assemblies	Athena Institute, University of Minnesota, Green Building Initiative	Athena software evaluates whole buildings and assemblies based on LCA for material manufacturing, including resource extraction and recycled content; related transportation; on-site construction; regional energy use, transportation, and other factors; building type and assumed lifespan; maintenance, repair, and replacement effects; demolition and disposal; and operating energy emissions and precombustion effects. www.athenasmi.org/tools/impactEstimator		X			X	X		X	X	X	X
Building for Environmental and Economic Sustainability (BEES)	National Institute of Standards and Technology (NIST), EPA Environmentally Preferable Purchasing Program	BEES 4.0 evaluates green building products categorized under 24 elements, taking into account U.S. methodology for U.S. life-cycle assessment. Evaluated impacts include global warming, acidification, eutrophication, fossil fuel depletion, indoor air quality, habitat alteration, ozone depletion, water intake, criteria air pollutants, smog, ecological toxicity, cancerous effects, and noncancerous effects. To date, NIST has evaluated and scored over 230 products on BEES environmental and economic performance. The EPA Office of Resources Conservation and Recovery (ORCR) currently uses BEES model components to assess benefits associated with beneficial use of fly ash, ground granulated blast furnace slag, and silica fume in concrete building products. www.bfrl.nist.gov/oae/software/bees			X	X				X	X	X	X
Beneficial Reuse Model (BenReMod)	University of Toledo	The Beneficial Reuse Model is a suite of modules for comparing different materials that can be used for road construction in different scenarios. Modules address life-cycle assessment; human cancer and noncancer risk and ecological toxicity potential (for freshwater aquatic, terrestrial, and freshwater sediment systems); and a multicriteria decision analysis with an algorithm for ranking scenarios where no material consistently performs better. Model development continues, in part under an EPA Region 5 grant. http://benremod.eng.utoledo.edu/BenReMod		X			X	X		X	X	X	X

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Free to Public													
Diesel Emissions Quantifier	EPA	The quantifier can calculate emission estimates of NO_x, PM, hydrocarbons, CO, and CO_2 for a fleet of highway/nonroad vehicles or marine vessels with various diesel emissions control technologies. The tool supports diesel retrofit projects but is not designed to meet regulatory requirements for air or transportation reporting. An associated spreadsheet lists retrofit and clean diesel technology parameters. http://cfpub.epa.gov/quantifier/view/info.cfm, www.epa.gov/otaq/diesel/documents/appl-fleet.xls	X			X	X				X		
EIO-LCA	Carnegie Mellon–Green Design Institute	The Economic Input Output–Life Cycle Assessment (EIO-LCA) contains a series of publicly available Web-based models that allow the user to estimate the overall environmental impacts from producing a certain dollar amount of any of 500 commodities or services in the United States. Most recent U.S. models (1997) reflect impacts in terms of 1997 U.S. dollars. www.eiolca.net		X		X	X	X	X	X	X	X	X
Energy and Materials Flow and Cost Tracker (EMFACT™)	Northeast Waste Management Officials' Association	EMFACT is designed to be used within companies for systematically tracking materials and energy use; releases, discharges, and wastes; and associated costs. The tool helps manufacturers to apply environmental management accounting when setting pollution prevention priorities, identifying value-added opportunities for sustainable production, and implementing materials and energy-efficiency improvements. www.newmoa.org/prevention/emfact/about.cfm		X			X	X		X	X		X
Green Remediation Evaluation Matrix	California Department of Toxic Substances Control	The Green Remediation Evaluation Matrix uses life-cycle thinking to evaluate treatment alternatives based on substance release/production, thermal releases, physical disturbances/disruptions, and resource depletion/gain (recycling). www.dtsc.ca.gov/OMF/Grn_Remediation.cfm			X		X	X		X	X	X	X

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Free to Public													
Greener Cleanups Matrix	Illinois Department of Environmental Protection	The Greener Cleanups Matrix helps maximize the environmental benefits of site remediation by evaluating the level of difficulty and feasibility (cost, schedule, and technical complexity) for actions associated with site assessment, planning and design, and cleanup. Matrix information is based on evaluation of certain cleanups from the LUST, Site Remediation Program (SRP), CERCLA, and RCRA programs using site-specific questionnaires, field visits, and consultations with green remediation practitioners. www.epa.state.il.us/land/greener-cleanups/matrix.pdf			**X**		**X**	**X**	**X**	**X**	**X**	**X**	**X**
Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET)	DOE Office of Energy Efficiency and Renewable Energy	GREET is a full life-cycle model to evaluate various vehicle and fuel combinations on a fuel-cycle/vehicle-cycle basis, including material recovery and vehicle disposal. For a given vehicle and fuel system, GREET calculates consumption of total energy (renewable and nonrenewable), fossil fuels, petroleum, coal, and natural gas; emissions of CO_2-equivalent GHG; and emissions of VOCs, CO, NO_x, PM_{10}, $PM_{2.5}$, and SO_x. The model includes more than 100 fuel production pathways and more than 70 vehicle/fuel systems. www.transportation.anl.gov/modeling_simulation/GREET/index.html		**X**		**X**	**X**	**X**	**X**		**X**		**X**
Greenscapes	EPA	This suite of tools includes six spreadsheet-based calculators for use in GreenScapes project decision making and cost comparisons regarding virgin materials versus environmentally preferable products or methods. Individual calculators address recycling and reusing landscape waste, resource conserving landscaping cost, erosion control, decking cost, subsurface drip irrigation cost, and pallets cost. www.epa.gov/epawaste/conserve/rrr/greenscapes/tools/index.htm		**X**		**X**				**X**		**X**	**X**

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Free to Public													
Hybrid2	DOE National Renewable Energy Laboratory, University of Massachusetts	The Hybrid Power System Simulation Model (version 2) simulates performance of renewable energy systems involving combinations of different electrical loads, types of wind turbines, photovoltaics, diesel generators, battery storage, and power conversion devices. The tool also compares long-term performance of comparable systems. www.nrel.gov/applying_technologies/engineering_finance.html		X			X		X				
Industrial Waste Management Evaluation Model (IWEM)	EPA	IWEM software helps determine the most appropriate waste management unit design to minimize or avoid adverse groundwater impacts. Evaluation parameters include liner types, hydrogeologic conditions of a site, and toxicity and expected leachate concentrations from anticipated waste constituents. IWEM lookup tables cover approximately 60 organic or inorganic constituents with established maximum contaminant levels. www.epa.gov/epawaste/nonhaz/industrial/tools/iwem/index.htm		X			X			X		X	
PaLATE Model	University of California–Berkeley	The PaLATE Model is an environmental life-cycle model for the transportation sector. EPA's ORCR currently uses the tool to assess benefits for reuse of industrial materials such as fly ash, foundry sand, construction and demolition debris in concrete pavement, asphalt pavement, and road base. www.ce.berkeley.edu/~horvath/palate.html			X	X				X	X		X
Performance Tracking Tool (PTT)	AFCEE	A simple Excel-based tool to evaluate systems to find whether contaminant rate removal is consistent with projected reduction rates and project costs. Using normalized data to graphically display the results, one can easily visualize the understanding of system operations with respect to existing environmental conditions. PTT can assist in decision making from the existing site-specific data by helping identify system end points in the remediation process, revise extraction points as needed, evaluate effects of remedial decisions, and then adjust accordingly to enhance the efficiency of the systems. www.afcee.af.mil/shared/media/document/AFD-100113-032.xls		X			X	X		X		X	X

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Free to Public													
RETScreen	Natural Resources Canada	RETScreen evaluates energy production and savings, costs, emission reductions, financial viability, and risk for various types of renewable-energy and energy-efficient technologies. The tool includes product, project, hydrology, and climate databases; a user manual; and a case study–based college/university–level training course. Companion information includes a training course on legal aspects of energy projects. www.retscreen.net		**X**			**X**	**X**	**X**				
SiteWise™ Sustainable Environmental Restoration Tool	Battelle, U.S. Navy, and USACE	SiteWise, a sustainable environmental remediation tool, is designed to calculate the environmental footprint of remedial alternatives generally used by the industry. The tool is a series of Excel sheets and currently provides a detailed baseline assessment of several quantifiable sustainability metrics including GHGs; energy usage; criteria air pollutants, including SO_x, NO_x, and PM; water usage; and accident risk. The tool is being jointly developed by Battelle, U.S. Navy, and USACE and expected to be available as freeware in spring 2010. (Battelle point of contact: Mohit Bhargava)		**X**			**X**	**X**	**X**	**X**	**X**		**X**

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Free to Public													
Sustainable Remediation Tool (SRT)	AFCEE	The SRT is designed to evaluate particular remediation technologies on the basis of sustainability metrics. The tool, programmed in Microsoft Office Excel®, facilitates sustainability planning and evaluation, which is intended to aid environmental professionals in achieving remedial process optimization goals and complying with regulations (e.g., EO 13423, which affects DOD). The SRT allows users to estimate sustainability metrics for specific technologies for soil and groundwater remediation. The current technology modules included in the SRT are excavation, soil vapor extraction, pump and treat, and enhanced bioremediation. Additional technologies and metrics are under development. For each technology and in each tier of evaluation, the following sustainability metrics are calculated: GHG emissions, total energy consumed, technology cost, safety/accident risk, and natural resource service. The SRT is structured into two levels of input complexity. Tier 1 calculations are based on rules-of-thumb information that are widely used in the environmental remediation industry. Tier 2 calculations are more detailed and incorporate site-specific factors. The output metrics are presented in both a nonnormalized and a normalized/cost-based format. www.afcee.af.mil/resources/technologytransfer/programsandinitiatives/sustainableremediation/index.asp		**X**			**X**	**X**		**X**	**X**	**X**	**X**
Waste Reduction Model (WARM)	EPA	EPA's ORCR uses WARM to assess benefits of the WasteWise program and specific benefits from reusing material such as fly ash, municipal solid waste recycling matter, and yard trimming compost (as a proxy for GreenScapes benefits). WARM also helps the public estimate GHG reductions of different waste management practices such as source reduction, recycling, combustion, composting, and landfilling for (currently 34) material types. epa.gov/climatechange/wycd/waste/calculators/Warm_home.html	**X**			**X**					**X**		**X**

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Proprietary/Restricted													
BalancE3™	ARCADIS	BalancE3 is a quantitative, Web-based tool used to evaluate different GSR approaches and incorporate them in remedy evaluation, selection, and design on a site-specific or portfolio-wide basis. It aggregates diverse sustainability metrics; provides the flexibility to prioritize any combination of eight metrics (energy, air emissions, water requirements, land impacts, waste generation and material consumption, long-term stewardship, health and safety, and life-cycle costs) for a given analysis; applies statistical methods and trade-off analyses to facilitate alternatives comparison; identifies key metrics to improve remedies through the practical application of greener remediation concepts; and provides a solution to calculate and manage carbon. (Point of contact: Kurt Beil, ARCADIS U.S. Inc., Newtown, PA]	**X**	**X**			**X**	**X**		**X**	**X**	**X**	**X**
Boustead Model	Boustead Consulting Ltd.	The Boustead Model is a tool for life-cycle inventory calculations of industrial processes. Version 5 links site-specific input to core data on fuel production, materials processing, stand-alone aspects, air emissions, water emissions, solid waste, solid waste regulated by the European Union, raw materials, fuels, feedstocks, and activity functions. www.boustead-consulting.co.uk/introduc.htm					**X**	**X**		**X**	**X**	**X**	**X**
Clean Me Green	Malcolm Pirnie, Inc., University of California–Santa Barbara Bren School of Environmental Science and Management	This spreadsheet tool was developed to improve the sustainability of site remediation by quantifying the cost, energy, and carbon savings associated with selecting or optimizing different remedial technologies. Use of this tool promotes creative and sustainably oriented thinking and emphasizes the benefits associated with greener approaches to remediation (Points of contact: Maryline Laugier and Elisabeth Hawley, Malcolm Pirnie]		**X**			**X**	**X**	**X**	**X**	**X**		

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Proprietary/Restricted													
Cleanup Sustainability Framework	DuPont, EPA Region 3	The framework was developed under a pilot project to evaluate sustainability of potential remedies and identify the optimal remedy at three RCRA sites in EPA Region 3. Metrics of a related credit/debit system focus on CO_2 equivalents, energy consumption, water use, soil use/ disposal, material use, and land. (Points of contact: Deb Goldblum, EPA Region 3 and David Ellis, DuPont]			X		X	X		X	X	X	X
GaBi	PE Consulting (Germany)	Originally developed by the University of Stuttgart, GaBi now is a commercially available suite of software and databases for life-cycle assessment (ISO 14040/44), carbon footprints (PAS 2050), GHG accounting, designs, energy efficiency, green supply chains, and material flow analysis. Software/database cost information is available through direct inquiries. www.gabi-software.com		X			X	X			X		X
GoldSET	Golder Associates Ltd.	GoldSET assesses the sustainability performance of remedial options based on site-specific scoring and weighting of environmental, social, and economic impacts. Over the past 3 years, GoldSET has been used in the United States, Canada, and Australia by the public and the private sectors. It is presently being customized to the requirements of a large corporation as well as for a Canadian federal agency. www.gold-set.com	X	X	X		X	X	X	X	X	X	X

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Proprietary/Restricted													
Green Remediation Analysis	EPA Region 9	Green Remediation Analysis is a spreadsheet tool for quantifying the environmental footprint of a remedy, using a life-cycle assessment approach. The spreadsheet tool may be used to compare alternative remedies at a cleanup site or to identify opportunities for reducing the environmental footprint of an existing remedy. Analytical parameters include resource use (fresh water, construction materials, remediation materials, gasoline and diesel fuel, and electricity), air emissions (CO_2, NO_x, SO_x, particulates, and air toxics), solid and hazardous waste generation, and wastewater discharge. Off-site manufacturing and transport are included in the analysis. Pilot testing of the spreadsheet tool is under way at three cleanup sites. When pilot testing is completed, the spreadsheets are intended for use by regulators, their contractors, and regulated site owners at other cleanup sites. (In development, Point of contact: Karen Scheuermann, EPA Region 9)					**X**	**X**		**X**	**X**		**X**

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Proprietary/Restricted													
Green Remediation Spreadsheets	EPA	This methodology considers contributions to the footprints from multiple components of remedies, including site investigation, construction, operations and maintenance and long-term monitoring. Both on- and off-site activities associated with each remedy component are included in the study. The method documents a process for estimating the footprints, provides the library of resources and reference values used in the study, documents findings specific to the evaluated remedies, and presents both site-specific and more generalized observations and lessons learned from conducting the study. Other primary objectives include, but are not limited to the following: • identifying or developing appropriate and applicable "footprint conversion factors" to calculate the footprints from various types of energy, materials, and services used in the remedy • estimating the footprints of up to 15 environmental parameters for three remedial alternatives • estimating the contribution to the various footprints from on-site activities, transportation, and nontransportation off-site activities • identifying those components of the various remedial alternatives that have a significant effect on the environmental footprint and those components that have a negligible effect on the environmental footprint • conducting a sensitivity analysis for variations in the remedy design information, footprint conversion factors, or other input values			X		X	X	X	X	X	X	X

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Proprietary/Restricted													
Sustainability Assessment Framework	CH2M Hill	The Sustainability Assessment Framework and methodology tool helps with both tasks by providing a framework for identifying sustainability criteria and a methodology for evaluating the greatest value sustainability options for the customer. This framework helps decision makers select from a universe of potential sustainability metrics (over 100) and includes a decision-making tool that facilitates input of life-cycle inventory information that can be integrated into a analytical hierarchy process for decision making and stochastic assessment of uncertainties. The decision-making process can be used for sustainability decisions alone or be used to integrate sustainability decisions with other project decision factors. (Point of contact: Paul Favara, CH2M Hill)		X	X	X	X	X	X	X	X	X	X
Net Environmental Benefit Analysis (NEBA)	DOE Oak Ridge National Laboratory, EPA National Center for Environmental Assessment, CH2MHill	NEBA is a risk management tool for evaluating trade-offs associated with environmental response actions. The tool can be supplemented with the nine NCP remedy selection criteria to evaluate site cleanup benefits related to increases in human use value, ecological service value, and economic value to society. (Points of contact: Rebecca Efroymson, Oak Ridge National Laboratory; Glenn Suter, NCEA; and Paul Favara, CH2M Hill]			X		X	X	X	X	X	X	X
SimaPro	Product Ecology Consultants	SimaPro is LCA software which collects, analyzes, and monitors the environmental performance of products and services. The tool can model and analyze complex life cycles in a systematic and transparent way, following the ISO 14040 series recommendations. www.pre.nl/simapro/simapro_lca_software.htm		X	X	X	X	X	X	X	X	X	X
Sustainability Assessment Tool	BP	This tool evaluates sustainability of existing remedies at specific sites. The tool has been used to evaluate remediation technologies such as (but not limited to) soil vapor extraction and pump and treat at an urban service station and sludge-pit treatment at a Superfund site in Texas. (In development, Point of contact: Stephanie Fiorenza, BP)			X		X			X	X	X	

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Proprietary/Restricted													
Sustainable Principles for Site Remediation	Good Earthkeeping Organization, Inc.	This commercial framework helps improve the efficiency of soil vapor extraction and multiphase extraction systems, with a focus on alternative methods for off-gas treatment. (In development, Point of contact: Lowell Kessel, Good EarthKeeping Organization, Inc.)			**X**		**X**	**X**			**X**		
Sustainable Remediation Assessment Tool	Haley & Aldrich	This tool evaluates the sustainability impacts of different remediation alternatives throughout a remediation project life cycle (including potential site redevelopment) and subsequently provides recommendations to reduce sustainability impacts. The tool addresses environmental, social, and economic impact indicators, for example, GHG emissions, criteria pollutant emissions, ecosystem disturbance, water consumption, natural resource use, solid waste production, impacts to the local community/ environmental justice, occupational risk, transportation risk, and total cost of remediation. (In development, Point of contact: Karin Holland, Haley & Aldrich, Inc.]		**X**			**X**	**X**	**X**	**X**	**X**	**X**	**X**
Sustainable Remediation: Cost/Benefit Analysis (CBA)	Shell Global Solutions (UK)	The CBA tool provides a risk-based framework to help balance decision making during remedy selection, with a focus on finding the economic optimum. (In development, Point of contact: David Reinke, Shell Global Solutions]			**X**		**X**	**X**		**X**	**X**	**X**	**X**

Title or common name	Sponsor	General description and access information	Web calculator	Decision software	Decision matrix	Policy/industry tool	Site specific	Energy efficiency	Renewable energy	Water	Air emission	Land & ecosystem	Materials & waste
Proprietary/Restricted													
Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)	EPA Office of Research and Development	EPA developed TRACI to assist in impact assessment for sustainability metrics, life-cycle assessment, industrial ecology, process design, and pollution prevention. The LCA process may include both the consideration of material and energy inputs and outputs and the impacts associated with the emissions related to these material and energy flows. An example of one such model is TRACI. Impacts fit generally into two categories: (1) depletion: impacts related to resource, land, and water use and (2) pollution: impacts related to ozone, global warming, smog, human and ecotoxicology, acidification, eutrophication, radiation, waste heat, odor, and noise. Many emissions or factors related to remediation, such as diesel emissions, fugitive VOCs, emissions associated with electricity production, methane emissions, as well as emissions associated production of materials and treatment chemicals, can be associated with these impact categories. www.epa.gov/nrmrl/std/sab/traci		X			X			X	X	X	X

Appendix B

Green and Sustainable Remediation Directory of Contacts and Resources

GREEN AND SUSTAINABLE REMEDIATION
DIRECTORY OF CONTACTS AND RESOURCES

This directory is a compilation of resources identified by the ITRC GSR Team. The resources include state contacts, private organizations, standards-setting organizations, and federal agencies. The ITRC GSR Team has attempted to locate useful and current information for a broad range of GSR contacts. Not all of these organizations have the same views or philosophies regarding GSR. ITRC provides these resource links as a research resource and does not endorse the positions of any of these organizations. Please send any additions, corrections, or updates to Tom O'Neill, tom.o'neill@dep.state.nj.us, Co-Leader of the ITRC GSR Team.

The directory is organized as follows:

- tribal nations
- states and territories
- federal agencies
- other organizations

Tribal Nations

Institute for Tribal Environmental Professionals (ITEP)
P.O. Box 15004
Flagstaff, AZ 86011-5004
Phone: 928-523-9555
Fax: 928-523-1266
itep@nau.edu
http://www4.nau.edu/itep/index.asp

The following link includes information on green remediation:
http://www4.nau.edu/itep/waste/docs/2010TWRAP_Booklet.pdf

National Pollution Prevention Roundtable–Tribal Workgroup
www.tribalp2.org/nppr/index.php

States and Territories

State contacts and resources are located in a variety of program areas, from brownfields to the Superfund. The reader should take care to contact each agency directly for the most up-to-date contact information. Nongovernmental resources with single state or regional ties are also found here. See the ITRC Team Member Directory in the next appendix and at www.itrcweb.org for more state contact information.

Alabama
For Alabama GSR information, contact ITRC GSR Team Member:
Bob Barnwell
AL Dept. of Environmental Management
334-270-5642
bbarnwell@adem.state.al.us

California
Department of Toxic Substance Control, www.dtsc.ca.gov/OMF/Grn_Remediation.cfm

Illinois
IL Environmental Protection Agency, www.epa.state.il.us/land/greener-cleanups

Illinois Environmental Regulatory Group, www.ierg.org
215 East Adams St.
Springfield, IL 62701
Phone: 217-522-5512
Fax: 217-522-5518
iergstaff@ierg.org

Indiana
Indiana Finance Authority–Brownfields Program, www.in.gov/ifa/brownfields/2351.htm

Midwestern States Environmental Consultants Association (MSECA), www.mseca.org
(This group may provide an effective communication conduit to state regulatory personnel in Midwestern states, particularly Indiana.)
11 S. Meridian Street
Indianapolis, IN 46204
Phone: 888-521-6802
Fax: 888-521-6803
Bruce Carter. Sustainability Committee Chair

Louisiana
For Louisiana GSR information, contact ITRC Team Member:
Adrienne Gossman
LA Dept. of Environmental Quality
504-736-7763
adrienne.gossman@la.gov

Massachusetts
For Massachusetts GSR information, contact ITRC Team Member:
Dorothy Allen
MA Dept. of Environmental Protection
617-292-5795
dorothy.t.allen@state.ma.us

Minnesota
Rebecca Bourdon, Hydrologist
MN Pollution Control Agency
Petroleum Remediation Program
520 Lafayette Rd., N
St. Paul, MN 55155
Rebecca.Bourdon @state.mn.us
www.pca.state.mn.us

New Jersey
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NJ Dept. of Environmental Protection, Site Remediation Program
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Trenton, NJ 08625-0413
Phone: 609-292-2150
Fax: 609-292-1975
tom.o'neill@dep.state.nj.gov
www.nj.gov/dep/srp

New York
NY Dept. of Environmental Conservation's Green Remediation Policy
www.dec.ny.gov/docs/remediation_hudson_pdf/der31.pdf

Oregon
OR Dept. of Environmental Quality
www.deq.state.or.us/lq/cu/greenremediation.htm

Pennsylvania
For Pennsylvania GSR information, contact ITRC GSR Team Member:
Jeff Painter
PA Dept. of Environmental Protection
717-783-9989
jepainter@state.pa.us

South Carolina
For South Carolina GSR information, contact ITRC GSR Team Member:
Keisha Long
SC Dept. of Health and Environmental Control
803-896-4872
longkd@dhec.sc.gov

Wyoming
For more information on GSR, contact ITRC Team member:
Scott Forister
WY Dept. of Environmental Quality
307-675-5678
sforis@wyo.gov
The following document has a brief discussion of GSR concepts: http://deq.state.wy.us/shwd/stp/STPDownloads/Guidance/Guidance_14.pdf

Federal Agencies

U.S. Environmental Protection Agency
The most comprehensive portal to GSR information and inks can be found at www.clu-in.org/greenremediation.

Carlos Pachon
U.S. Environmental Protection Agency
OSRTI
1200 Pennsylvania Avenue, NW
5203P
Washington, DC 20460
Phone: 703-603-9904
Fax: 703-603-9135
pachon.carlos@epa.gov

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RPM
5 Post Office Square
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Boston, MA 02109-3912
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Fax: 617-918-0754
lombardo.ginny@epa.gov

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New York, NY 10007
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diforte.nicoletta@epa.gov

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Hilary Thornton
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3HS23
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Fax: 215-814-3002
thornton.hilary@epa.gov

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akindele.femi@epa.gov

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WMD/SRTSB
Atlanta, GA 30303
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Superfund Division/Brownfields Branch
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Chicago, IL 60604
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Fax: 312-886-4071
bradley.brad@epa.gov

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Dallas, TX 75202
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Fax: 214-665-7330
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1595 Wynkoop St.
8EPR-SR
Denver, CO 80202
Phone: 303-312-6571
Fax: 303-312-6897
costanzi.frances@epa.gov

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Karen Scheuermann
75 Hawthorne St.
WST-4
San Francisco, CA 94105
Phone: 415-972-3356
Fax: 415-947-3530
scheuermann.karen@epa.gov

Region 10
Sean Sheldrake
U.S. EPA, Region 10
1200 Sixth Ave., Suite 900
Seattle, WA 98101
Phone: 206-553-1220
sheldrake.sean@epa.gov

Department of Defense

Air Force
Air Force Center for Engineering and the Environment (AFCEE)

AFCEE has a number of GSR-related pages including the following:

GSR–A link to the Sustainable Remediation Tool (SRT) can be found at www.afcee.af.mil/resources/technologytransfer/programsandinitiatives/sustainableremediation/greenandsustainableremed/index.asp

Sustainability, www.afcee.af.mil/resources/sustainability

Sustainable Communities, www.afcee.af.mil/resources/sustainability/communities/index.asp

Army
Army Corps of Engineers
Decision Framework for Incorporating Green and Sustainable Practices
www.environmental.usace.army.mil/interim_guidance.htm

Army Environmental Command
A search here will turn up several case studies and the following strategic plan document that references green remediation under "future directions": http://aec.army.mil/usaec/cleanup/10stratplan.pdf

Navy
GSR Portal—Numerous GSR resources found here including a link to the SiteWise tool www.ert2.org/t2gsrportal

Department of Energy

DOE Main Page, www.energy.gov/index.htm
DOE Office of Environmental Management (EM) Page, www.em.doe.gov/Pages/EMHome.aspx
(No reference or policy found as green or sustainable remediation on either page—-green remediation information coming soon.)

Other Organizations

Association of State and Territorial Solid Waste Management Officials (ASTSWMO)
www.astswmo.org/programs_sustainability.htm
Greener Cleanups Task Force
Heather Nifong, Chair
Phone: 217-785-4729
heather.nifong@illinois.gov

Sustainable Remediation Forum (SURF), www.sustainableremediation.org

Sustainable Remediation Forum–UK,
www.claire.co.uk/index.php?option=com_content&view=article&id=182&Itemid=78
www.nicole.org/sustainableremediation

ConSoil 2010 Conference, www.consoil.olanis.de

ASTM International
Committee E50 on Environmental Assessment, Risk Management and Corrective Action, www.astm.org/COMMIT/COMMITTEE/E50.htm
www.astm.org/SNEWS/MA_2010/bassettgreen_ma10.html
Daniel Smith, Staff Manager
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Appendix C

ITRC GSR Team Contacts

ITRC GSR TEAM CONTACTS

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Appendix D

Acronyms

ACRONYMS

ADEM	Alabama Department of Environmental Management
AFCEE	Air Force Center for Engineering and the Environment
ARRA	American Reinvestment and Recovery Act
ASTM	ASTM International (formerly American Society for Testing and Materials)
ASTSWMO	Association of State and Territorial Solid Waste Management Officials
BEES	Building for Environmental and Economic Sustainability
BMP	best management practice
BWSC	Bureau of Waste Site Cleanup
CBA	cost/benefit analysis
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLIOS	complex large-scale interconnected, open socio-technical
CLU-IN	Contaminated Site Clean-Up Information
CSM	conceptual site model
DER	Division of Environmental Remediation
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DTSC	Department of Toxic Substances Control
ECOS	Environmental Council of States
EIO-LCA	Economic Input Output–Life Cycle Analysis
EISB	enhanced in situ bioremediation
EM-CX	Environmental and Munitions Center of Expertise
EMFACT	Energy and Materials Flow and Cost Tracker
EO	Executive Order
EPA	U.S. Environmental Protection Agency
ERIS	Environmental Research Institute of States
ERP	Environmental Restoration Program
ESTCP	Environmental Security Technology Certification Program
FFEO	Federal Facilities Enforcement Office
FFRRO	Federal Facilities Restoration and Reuse Office
FRTR	Federal Remediation Technologies Roundtable
GHG	greenhouse gas
GR	green remediation
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GREM	Green Remediation Evaluation Matrix
GRIT	Green Remediation Implementation Team
GSR	green and sustainable remediation
GSR2	Green Sustainable Remediation and Redevelopment
ISO	International Organization for Standards
ITRC	Interstate Technology & Regulatory Council
IWEM	Industrial Waste Management Evaluation Model
LCA	life-cycle assessment
LUST	leaking underground storage tank
MassDEP	Massachusetts Department of Environmental Protection
MNA	monitored natural attenuation
MPCA	Minnesota Pollution Control Agency

NAVFAC	Naval Facilities Engineering Command
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEBA	net environmental benefits analysis
NICOLE	Network for Industrially Contaminated Land in Europe
NIST	National Institute of Standards and Technology
NO_x	nitrogen oxides
NPL	National Priorities List
NRD	natural resource damage
OACSIM	Office of the Assistant Chief of Staff for Installation Management
OEM	Office of Emergency Management
O&M	operations and maintenance
ORCR	Office of Resources Conservation and Recovery
OSRE	Office of Site Remediation Enforcement
OSRTI	Office of Superfund Remediation and Technology Innovation
OSWER	Office of Solid Waste and Emergency Response
PBR	performance-based remediation
PM	particulate matter
$PM_{2.5}$	particulate matter less than 2.5 µm in aerodynamic diameter
PM_{10}	particulate matter less than 10 µm in aerodynamic diameter
PRP	Petroleum Remediation Program
PTT	Performance Tracking Tool
RCRA	Resource Conservation and Recovery Act
RPM	remedial project manager
RSEI	Risk-Screening Environmental Indicator
SERDP	Strategic Environmental Research and Development Program
SO_x	sulfur oxides
SRNL	Savannah River National Laboratory
SRP	Site Remediation Program
SRT	Sustainable Remediation Tool™
SURF	Sustainable Remediation Forum
SuRF-UK	Sustainable Remediation Forum–United Kingdom
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
USACE	U.S. Army Corps of Engineers
USAF	U.S. Air Force
VOC	volatile organic compound
WARM	Waste Reduction Model
WDNR	Wisconsin Department of Natural Resources
WISC	Wisconsin's Initiative for Sustainable Cleanups