# Green Remediation:
## Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites

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# Green Remediation:
# Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites

Technology Primer

# *Green Remediation:*

# *Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites*

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An electronic version of this primer can be downloaded from OSRTI's and BTSC's websites at http://cluin.org/greenremediation or http://www.brownfieldstsc.org. To obtain a copy of the *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* technology primer (free of charge), contact:

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As a primer, this document provides topical introductory information rather than guidance. EPA recommends that users refer to applicable regulations, policies, and guidance documents regarding selection of cleanup remedies and implementation of cleanup actions; selected references and additional resources are provided herein. This primer was subjected to the Agency's administrative and expert review and was approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

*Cover photo:* Ground water remediation at the former St. Croix Alumina Plant in St. Croix, VI, relies on wind-driven turbine compressors to drive pneumatic pumps in recovery wells; recovered oil is reclaimed and used as feedstock at an adjacent petroleum refinery.

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# Acronyms and Abbreviations

| | |
|---|---|
| ARAR | applicable or relevant and appropriate requirement |
| BMP | best management practice |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended |
| $CH_4$ | methane |
| $CO_2$ | carbon dioxide |
| CSP | concentrating solar power |
| DOD | U.S. Department of Defense |
| DOE | U.S. Department of Energy |
| EERE | U.S. DOE Office of Energy Efficiency and Renewable Energy |
| EPA | U.S. Environmental Protection Agency |
| ET | evapotranspiration |
| FY | fiscal year |
| GHG | greenhouse gas |
| IDW | investigation derived waste |
| kW | kilowatt |
| kWh | kilowatt-hour |
| LEED | Leadership in Energy and Environmental Design |
| LFG | landfill gas |
| LID | low impact development |
| MNA | monitored natural attenuation |
| mph | miles per hour |
| MW | megawatt |
| $N_2O$ | nitrous oxide |
| NCP | National Oil and Hazardous Substances Pollution Contingency Plan |
| NPL | National Priorities List |
| NREL | U.S. DOE National Renewable Energy Laboratory |
| O&M | operation and maintenance |
| OSRTI | U.S. EPA Office of Superfund Remediation and Technology Innovation |
| OSWER | U.S. EPA Office of Solid Waste and Emergency Response |
| P&T | pump-and-treat |
| PRB | permeable reactive barrier |
| PV | photovoltaic |
| RCRA | Resource Conservation and Recovery Act of 1976, as amended |
| ROD | record of decision |
| RSE | remedial system evaluation |
| SVE | soil vapor extraction |
| UST | underground storage tank |
| UV | ultraviolet |
| VOC | volatile organic compound |
| WTE | waste-to-energy |

# Section 1: Introduction

As part of its mission to protect human health and the environment, the U.S. Environmental Protection Agency (EPA or "the Agency") 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 Agency's strategic plan for compliance and environmental stewardship (U.S. 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.

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 Agency 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.

> Green Remediation: *The practice of considering all environmental effects of remedy implementation and incorporating options to maximize net environmental benefit of cleanup actions.*

Green remediation reduces the demand placed on the environment during cleanup actions, otherwise known as the "footprint" of remediation, and avoids the potential for collateral environmental damage. The potential footprint encompasses impacts long known to affect environmental media:

- Air pollution caused by toxic or priority pollutants such as particulate matter and lead,
- Water cycle imbalance within local and regional hydrologic regimes,
- Soil erosion and nutrient depletion as well as subsurface geochemical changes,
- Ecological diversity and population reductions, and
- Emission of carbon dioxide ($CO_2$), nitrous oxide ($N_2O$), methane ($CH_4$), and other greenhouse gases contributing to climate change.

Opportunities to increase sustainability exist throughout the investigation, design, construction, operation, and monitoring phases of site remediation regardless of the selected cleanup remedy. As cleanup technologies continue to advance and incentives evolve, green remediation strategies offer significant potential for increasing the net benefit of cleanup, saving project costs, and expanding the universe of long-term property use or reuse options without compromising cleanup goals.

## ■ *Purpose of Primer*

This primer outlines the principles of green remediation and describes opportunities to reduce the footprint of cleanup activities throughout the life of a project. Best management practices (BMPs) outlined in this document help decision-makers, communities, and other stakeholders (such as project managers, field staff, and engineering contractors) identify new strategies in terms of sustainability. These strategies complement rather than replace the process used to select primary remedies that best meet site-specific cleanup goals. The primer identifies the range of alternatives available to improve sustainability of cleanup activities and helps decision-makers balance the alternatives within existing regulatory frameworks. To date, EPA's sustainability initiatives have addressed a broader scope or focused on selected elements of green remediation such as clean energy.

The primer strives to cross educate remediation and reuse decision-makers and other stakeholders about green remediation using a "whole-site" approach that reflects reuse goals. Greater awareness of the opportunities helps remediation decision-makers address the role of cleanup in community revitalization, and helps revitalization project managers maintain an active voice during all stages of remediation decision-making. To maximize sustainability, cleanup and reuse options are considered early in the planning process, enabling BMPs during remediation to carry forward (Figure 1).

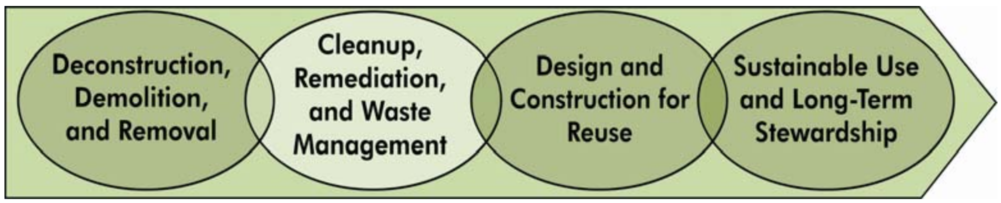


*Figure 1. BMPs of green remediation may be used throughout the stages of land revitalization, as a contaminated site progresses toward sustainable reuse or new use.*

Best practices can be incorporated into all phases of remediation, including site investigation, remedy construction, operation of treatment systems, monitoring of treatment processes and progress, and site close-out. Site-specific green remediation strategies can be documented in service or vendor contracts as well as project materials such as site management plans.

To help navigate the range of green remediation opportunities, this primer provides tools for daily operations and introductory information on the use of renewable energy resources. Profiles of site-specific implementation of green remediation strategies are provided throughout the document to help federal and state agencies, local communities, and other stakeholders learn from collective experiences and successes. As new information becomes available, additional profiles will be available online on EPA's *Green Remediation* web site (http://www.cluin.org/greenremediation). The document also describes the rapidly expanding selection of incentives for strategy implementation and provides a list of additional resources [bracketed number resources] in addition to direct (parenthetical) references.

## ■ *Overview of Green Remediation*

Strategies for green remediation rely on sustainable development whereby environmental protection does not preclude economic development, and economic development is ecologically viable today and in the long run. The Agency has compiled information from a range of EPA programs supporting sustainability along the categories of the built environment; water, ecosystems and agriculture; energy and environment; and materials and toxics. [General Resource 1, Section 8] Many programs, tools, and incentives are available to help governments, businesses, communities, and individuals serve as good environmental stewards, make sustainable choices, and effectively manage resources.

*Sustainable development meets the need of the present without compromising the need of future generations, while minimizing overall burdens to society.*

Use of green remediation BMPs helps to accelerate the pace of environmental protection in accordance with the Agency's strategic plan for improving environmental performance of business sectors. Green remediation builds on environmentally conscious practices already used across business and public sectors, as fostered by the Agency's Sectors Program, and promotes incorporation of state-of-the-art methods for:

- Conserving water,
- Improving water quality,
- Increasing energy efficiency,
- Managing and minimizing toxics,
- Managing and minimizing waste, and
- Reducing emission of criteria air pollutants and greenhouse gases (GHGs) (U.S. EPA National Center for Environmental Innovation, 2006).

Increasing concerns regarding climate change have prompted major efforts across the globe to reduce GHG emissions caused by activities such as fossil fuel consumption. [2] The Agency'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 *Executive Order 13423: Strengthening Federal Environmental, Energy, and Transportation Management* (Executive Order 13423, 2007). [3, 4] Accordingly, one category of EPA's evolving practices for green remediation places greater emphasis on approaches that reduce energy consumption and GHG emissions:

- Designing treatment systems with optimum efficiency and modifying 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 byproducts such as methane gas or secondary materials, and
- Participating in power generation or purchasing partnerships offering electricity from renewable resources.

Green remediation strategies also reflect increased recognition of the need to preserve the earth's natural hydrologic cycle. Best management of remediation activities includes water conservation measures, stormwater runoff controls, and recycling of treatment process water. Techniques for maintaining water balance are based on requirements of federal and state ground water protection and management programs and on recent climate-change findings by government agencies and organizations such as the U.S. Department of Agriculture, U.S. Geological Survey, and National Ground Water Association. [5] The strategies build on ground water and surface water management requirements under the Clean Water Act and Safe Drinking Water Act as well as water conservation goals set by Executive Order 13423.

*BMPs of green remediation help balance key elements of sustainability:*

- *Resource conservation measured by "water intensity," the amount of water necessary to remove one pound of contaminant, or by "soil intensity," the amount of soil displaced or disturbed to remove one pound of contaminant,*
- *"Material intensity" measured by the amount of raw materials extracted, processed, or disposed of for each pound of contaminant treated, and*
- *Energy efficiency measured by the amount of energy needed to remove one pound of contaminant.*

# ■ *Universe of Sites*

Green remediation promotes adoption of sustainable strategies at every site requiring environmental cleanup, whether conducted under federal, state, or local cleanup programs or by private parties. Past spills, leaks, and improper management or disposal of hazardous materials and wastes have resulted in contaminated land, water, and/or air at hundreds of thousands of sites across the country. EPA and its state, tribal, and territorial partners have developed a number of programs to investigate and remediate these sites.

Most federal cleanup programs are conducted under statutory authority of the Resource Conservation and Recovery Act (RCRA ) of 1976, as amended by the Hazardous and Solid Waste Amendments of 1984; Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986; and Small Business Liability Relief and Brownfields Revitalization Act of 2001. Most states maintain parallel statutes providing for voluntary and mandatory cleanup as well as brownfield and reclamation programs. In addition, most states have attained authority to implement federal mandates under the RCRA corrective action and underground storage tank programs.

Remediation activities in the United States may be grouped into seven major cleanup programs or market segments implemented under different federal or state statues. These market segments are described in *Cleaning Up the Nation's Waste Sites: Markets and Technology Trends,* along with estimates of the number of sites under each major cleanup program (U.S. EPA/OSWER, 2004). Principles and BMPs of green remediation can be applied at sites in each of the market segments, although administrative, institutional, and remedy-selection decision criteria may vary across programs. Based on this report and other summary data, EPA estimates the approximate number of sites requiring remediation under each of the major cleanup programs.

*Superfund Sites:* As of 2005, nearly 3,000 CERCLA records of decision (RODs) and ROD amendments had been signed. RODs document treatment, containment, and other remedies for contaminated materials at approximately 1,300 of the more than 1,500 sites historically listed on the National Priorities List (NPL), including those delisted over the years. Superfund cleanups also encompass "removals," which are short-term actions to address immediate threats and emergency responses. Since its inception, the program has undertaken more than 9,400 removal actions.

*RCRA Sites:* EPA estimates that more than 3,700 regulated hazardous waste treatment, storage, and disposal facilities are expected to need corrective action under the RCRA Corrective Action Program.

*Underground Storage Tank Sites:* Through September 2007, over 474,000 releases of hazardous substances have been reported at sites with underground storage tanks. Of these, 365,000 cleanups have been completed, leaving approximately 109,000 sites with reported releases to be remediated. In recent years, between 7,000 and 9,000 new reports of releases were received annually.

*Department of Defense Sites:* The U.S. Department of Defense (DOD) estimates that investigations and/or cleanups are planned or underway at nearly 8,000 areas. These areas are located on hundreds of active and inactive installations and formerly used defense sites.

**Department of Energy Sites:** The U.S. Department of Energy (DOE) has remediated contaminated areas at more than 100 installations and other locations. The Department has identified approximately 4,000 contaminated or potentially contaminated areas on 22 installations and other locations. Most of DOE's remediated areas will require ground water treatment and monitoring or other long-term stewardship efforts.

**Other Federal Agency Sites:** EPA estimates that there are more than 3,000 contaminated sites, located on 700 federal facilities, potentially requiring remediation. These facilities are distributed among 17 federal agencies. Investigations at many of these facilities are not complete. These estimates do not include an estimated 8,000-31,000 abandoned mine sites, most of which are located on federal lands.

**State, Brownfield, and Private Sites:** EPA estimates that during 2006 and 2007 alone cleanups were completed at over 18,900 sites, totaling over 250,000 acres, through state and tribal response programs. Institutional controls have also been put in place where required. EPA's investment in brownfields, exceeding 1.3 billion dollars through 2007, has leveraged more than $10.3 billion in cleanup and redevelopment funding and financed assessment and/or cleanup of more than 4,000 properties.

Cleanups across these market segments involve a wide range of pollution sources and site types such as neighborhood dry cleaners and gas stations, former industrial sites in urban areas, metals-contaminated mining sites, and large DOD, DOE, and industrial facilities that are downsized or decommissioned. Cleanup and reuse of these sites will consume significant amounts of energy, considerably impact natural resources, and affect the infrastructures of surrounding communities.

# Section 2: Sustainability of Site Remediation

Green remediation focuses on maximizing the net environmental benefit of cleanup, while preserving remedy effectiveness as part of the Agency's primary mission to protect human health and the environment. Site-specific strategies must take into account the unique challenges and characteristics of a site; no single solution exists. At all sites, however, key opportunities for integrating core elements of green remediation can be found when designing and implementing cleanup measures. Regulatory criteria and standards serve as a foundation for building green practices.

## ■ *Core Elements of Green Remediation*

Green remediation results in effective cleanups minimizing the environmental and energy footprints of site remediation and revitalization. Sustainable practices emphasize the need to more closely evaluate core elements of a cleanup project; compare the site-specific value of conservation benefits gained by different strategies of green remediation; and weigh the environmental trade-offs of potential strategies. Green remediation addresses six core elements (Figure 2):

*Energy requirements of the treatment system*

- Consider use of optimized passive-energy technologies (with little or no demand for external utility power) that enable all remediation objectives to be met,
- Look for energy efficient equipment and maintain equipment at peak performance to maximize efficiency,
- Periodically evaluate and optimize energy efficiency of equipment with high energy demands, and
- Consider installing renewable energy systems to replace or offset electricity requirements otherwise met by the utility.


*Figure 2. Best management practices of green remediation balance core elements of a cleanup project.*

*Air emissions*

- Minimize use of heavy equipment requiring high volumes of fuel,
- Use cleaner fuels and retrofit diesel engines to operate heavy equipment, when possible,
- Reduce atmospheric release of toxic or priority pollutants (ozone, particulate matter, carbon monoxide, nitrogen dioxide, sulfur dioxide, and lead), and
- Minimize dust export of contaminants.

*Water requirements and impacts on water resources*

- Minimize fresh water consumption and maximize water reuse during daily operations and treatment processes,
- Reclaim treated water for beneficial use such as irrigation,
- Use native vegetation requiring little or no irrigation, and
- Prevent impacts such as nutrient loading on water quality in nearby water bodies.

*Land and ecosystem impacts*

- Use minimally invasive *in situ* technologies,
- Use passive energy technologies such as bioremediation and phytoremediation as primary remedies or "finishing steps," where possible and effective,
- Minimize soil and habitat disturbance,
- Minimize bioavailability of contaminants through adequate contaminant source and plume controls, and
- Reduce noise and lighting disturbance.

*Material consumption and waste generation*

- Use technologies designed to minimize waste generation,
- Re-use materials whenever possible,
- Recycle materials generated at or removed from the site whenever possible,
- Minimize natural resource extraction and disposal, and
- Use passive sampling devices producing minimal waste, where feasible.

*Long-term stewardship actions*

- Reduce emission of $CO_2$, $N_2O$, $CH_4$, and other greenhouse gases contributing to climate change,
- Integrate an adaptive management approach into long-term controls for a site,
- Install renewable energy systems to power long-term cleanup and future activities on redeveloped land,
- Use passive sampling devices for long-term monitoring, where feasible, and
- Solicit community involvement to increase public acceptance and awareness of long-term activities and restrictions.

Green remediation requires close coordination of cleanup and reuse planning. Reuse goals influence the choice of remedial action objectives, cleanup standards, and the cleanup schedule. In turn, those decisions affect the approaches for investigating a site, selecting and designing a remedy, and planning future operation and maintenance of a remedy to ensure its protectiveness.

### Green Remediation Objectives

- Achieve remedial action goals,
- Support use and reuse of remediated parcels,
- Increase operational efficiencies,
- Reduce total pollutant and waste burdens on the environment,
- Minimize degradation or enhance ecology of the site and other affected areas,
- Reduce air emissions and greenhouse gas production,
- Minimize impacts to water quality and water cycles,
- Conserve natural resources,
- Achieve greater long-term financial return from investments, and
- Increase sustainability of site cleanups.

Site cleanup and reuse can mutually support one another by leveraging infrastructure needs, sharing data, minimizing demolition and earth-moving activities, re-using structures and demolition material, and combining other activities that support timely and cost-effective cleanup and reuse. Early consideration of green remediation opportunities offers the greatest flexibility and likelihood for related practices to be incorporated throughout a project life. While early planning is optimal, green strategies such as engineering optimization can be incorporated at any time during site investigation, remediation, or reuse.

## ■ *Regulatory Requirements for Cleanup Measures*

EPA's green remediation strategies build on goals established by federal statutes and regulatory programs to achieve greater net environmental benefit of a cleanup. Although remedy selection criteria and performance standards vary in accordance with statutory or regulatory authority, goals remain common among the cleanup programs. Section 121 of CERCLA, for example, requires that remedies:

- Protect human health and the environment,
- Attain applicable or relevant and appropriate requirements (ARARs) or provide reasons for not achieving ARARs,
- Are cost effective,
- Utilize permanent solutions, alternative solutions, or resource recovery technologies to the maximum extent possible, and
- Satisfy the preference for treatment that reduces the toxicity, mobility, or volume of the contaminants as opposed to an alternative that provides only for containment. [6]

Pursuant to CERCLA, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) also identifies nine evaluation criteria to be used in a detailed analysis of cleanup alternatives:

- Overall protection of human health and the environment,
- Compliance with ARARs,
- Long-term effectiveness and permanence,
- Reduction of toxicity, mobility, or volume through treatment,
- Short-term effectiveness,
- Implementability,
- Cost,
- State acceptance, and
- Community acceptance. [7]

Similarly, several evaluation criteria are used under the Agency's RCRA Corrective Action Program to determine the most favorable alternative for corrective measures: long-term reliability and effectiveness; reduction in toxicity, mobility, or volume of wastes; short-term effectiveness; implementability; cost; community acceptance; and state acceptance.

EPA's strategic plan for compliance and environmental stewardship relies on the Agency's cleanup programs to significantly reduce hazardous material use, energy and water consumption, and GHG intensity by 2012. In addition, the Agency's strategy regarding clean air and global climate change calls for collaboration with DOE and organizations to help the United States reduce its GHG intensity from 2002 levels by 18% by 2012. These partnerships encourage sound choices regarding energy efficient equipment, policies and practices, and transportation. BMPs of green remediation provide additional tools for making sustainable choices within this statutory, regulatory, and strategic framework.

## ■ *Expanded Consideration of Energy and Water Resources*

Site remediation and revitalization decisions also must comply with more recent federal and state statutes requiring or recommending reductions in energy and water consumption as well as increased use of renewable energy. The Energy Policy Act of 2005, for example, promotes energy conservation nationwide and increases availability of energy supplies. [8] The Act recognizes that energy production and environmental protection are non-exclusive national goals and encourages energy production and demand reduction by promoting new technology, more efficient processes, and greater public awareness (Capital Research, 2005).

A number of policies are in place to ensure that federal activities meet greener objectives. EPA's strategic plan recognizes that implementing provisions of the Energy Policy Act is a major undertaking involving increased partnership with DOE. DOE's Office of Energy Efficiency and Renewable Energy (EERE) reports that the Act's major provisions, as strengthened by Executive Order 13423, require federal facilities (sites owned or operated by federal agencies) to:

- Reduce facility energy consumption per square foot (a) 2% each year through the end of 2015 or a total of 20% by the end of fiscal year (FY) 2015 relative to 2003 baseline; and (b) 3% per year through the end of 2015 or a total of 30% by the end of FY 2015 relative to 2003 baseline (including industrial and laboratory facilities),
- Expand use of renewable energy to meet (a) no less than 3% of electricity demands in FY 2007-2009, 5% in FY 2010-FY 2012, and 7.5% in 2013 and thereafter; and (b) at least 50% of the renewable energy requirements through new renewable sources,
- Reduce water consumption intensity by 2% each year through the end of FY 2015 or 16% by the end of FY 2015 (relative to 2007 baseline) beginning in 2008,
- Employ electric metering in federal buildings by 2012,
- Apply sustainable design principles for building performance standards, and
- Install 20,000 solar energy systems by 2010.

The Energy Independence and Security Act of 2007 sets additional goals regarding energy consumption and associated GHG emissions, including increased use of alternative fuels for vehicles and new standards for energy efficiency in buildings. [9] The Act also promotes accelerated research and development of alternative energy resources (primarily solar, geothermal, and marine energy technologies) and provides grants to develop technologies for large-scale $CO_2$ capture from industrial sources. To date, 24 states plus the District of Columbia have implemented policies for renewable portfolio standards requiring electricity providers to obtain a minimum percentage of their power from renewable energy resources by a certain date. Four additional states have established non-regulatory goals for adopting renewable energy. [10]

Federal agencies such as the EPA, DOD, DOE, U.S. Department of Agriculture, and General Services Administration are working to develop mechanisms for meeting energy and water conservation goals and deadlines across both government and private sectors. Voluntary or required participation in related federal, state, and a growing number of municipal initiatives provides significant opportunities for integrating green practices into site remediation and reuse.

EPA's sustainability strategy encourages "demand-driven" and participatory decision-making using a systematic approach and life-cycle perspective to evaluate chemical, biological, and economic interactions at contaminated sites. Accordingly, EPA is collaborating with public and private partners to establish benchmarks, identify best practices, and develop the models, tools, and metrics needed to reach the goals of green remediation. The Agency also is compiling new information to quantify the net environmental benefit gained by site-specific reductions in fossil fuel consumption and to estimate related contributions in meeting national climate-change goals. On a local level, EPA regions are working with business and community partners to identify site-specific opportunities for demonstrating and applying these practices.

# Section 3: Site Management Practices

BMPs of green remediation help ensure that day-to-day operations during all cleanup phases maximize opportunities to preserve and conserve natural resources while achieving the cleanup's mission of protecting human health and the environment. Opportunities to implement the practices are not restricted to cleanups involving media treatment; for example, the practices can apply to removal actions involving primarily institutional controls or short-term soil excavation with offsite disposal. In these cases, the cleanup approach is similar to one used for sustainable and energy efficient construction projects.

Many of the strategies already are used to some degree in site cleanup, although the practices are not necessarily labeled "green." For example, selection of native rather than non-native plants for remedies such as vegetative landfill covers or soil excavation and revegetation significantly reduces the need to consume water for irrigation purposes – one of the key BMPs for water conservation.

Each site management plan can incorporate practices addressing core elements of green remediation with periodic review and update as new opportunities arise. An adaptive approach to site management planning enables early plans, in many cases initiated during emergency removal actions, to be expanded throughout remediation and extended into long-term stewardship controls. Each plan can outline site-specific procedures to:

- Reduce air emissions and energy use,
- Demonstrate water quality preservation and resource conservation,
- Establish near-term improvements to the ecosystem that carry forward into site revitalization, and
- Reduce material consumption and waste generation.

*Site management plans can specify BMPs for daily operations that meet the goals of green remediation.*

Many of the BMPs and high performance criteria for site management draw on elements of a variety of programs:

- U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system for new or existing building construction,
- Joint EPA/DOE Energy Star® product ratings, guidelines for energy management in buildings and plants, and general designs for energy efficient commercial buildings,
- EPA's GreenScapes for landscaping approaches that preserve natural resources while preventing waste and pollution, and
- Smart Growth principles helping to reduce urban sprawl. [11-14]

BMPs also stem from new or ongoing federal initiatives to reduce GHG emissions and energy consumption and generally promote green practices and products within market sectors. Examples include joint EPA/DOE recommendations regarding green construction of federal buildings; requirements for General Services Administration procurement of green products and services; and EPA partnership with trade associations of major manufacturing and service sectors such as the construction industry's Associated General Contractors of America. [15-17]

Costs for implementing the "extra steps" of green remediation range considerably but can be equal to or below those of conventional cleanup practices, particularly following an initial learning curve. Effective strategies consider site-specific conditions and requirements, long-term investment returns, energy efficiency, and product or service lifecycles. Efficiency improvements under DOE energy-savings performance contracts, for example, are estimated to provide federal net savings of $1.4 billion. The savings result from implementing recommendations of energy service companies under contracts extending up to 25 years (U.S. DOE/EERE, 2007). Site-specific case studies show that BMPs applicable to green remediation can result in immediate and long-term savings:

- Capital costs for a 3-kilowatt (kW) solar system at the Pemaco Superfund site in Maywood, CA, were recovered after one year of operation. Nine months of solar operations provided sufficient electricity to cover one month of operating the site's treatment building, which contains controls for soil heating and ground water pumping and treatment (U.S. EPA/OSWER, 2008(a)).
- Recent engineering optimization of the ground water pumping and treatment system used at the Havertown PCP Site in Havertown, PA, provides a savings of $32,000 each year. Cost reductions are attributed to lower electricity consumption as well as fewer purchases of equipment parts and process chemicals (U.S. EPA/OSWER, 2006).
- Low impact development strategies involving open space preservation and cluster design result in total capital cost savings of 15-80%, according to the majority of 17 case studies conducted by EPA. The savings are generated by reduced costs for site grading and preparation, stormwater infrastructure, site paving, and landscaping (U.S. EPA/Office of Water, 2007).

One example of innovative strategies used to incorporate BMPs common across market sectors is provided by the passive solar biodiesel-storage shed design (Figure 3) developed by Piedmont Biofuels, a North Carolina community cooperative using and encouraging the use of clean, renewable biofuels. Green elements of the design include cob walls comprising sand, clay, and straw to ensure biodiesel storage at interior temperatures remaining above 20° F; a foundation of locally obtained stone mortared with clay; a low-cost galvanized metal roof for heat retention; and a southern overhang to prevent excess solar gain in summer. When needed, portable solar systems can provide electricity to generate additional interior heat. [18]

Incorporating green remediation into cleanup procurement documents is one way to open the door for best practices in the field. In accordance with federal strategies for green acquisition (Executive Order 13423, 2007), purchasing agreements supporting site cleanup and revitalization should give preference to:

- Products with recycled content,
- Biobased products,
- Alternative fuels,
- Hybrid and alternative fuel vehicles,
- Non-ozone depleting substances,
- Renewable energy,
- Water efficient, energy efficient Energy Star® equipment and products with the lowest watt stand-by power, and
- All services that include supply or use of these products.

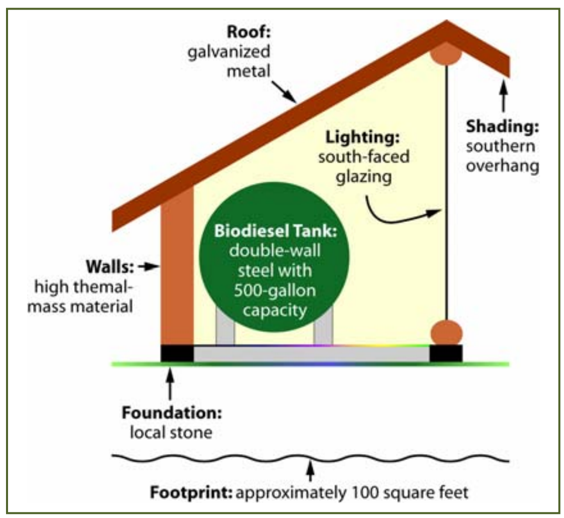


*Figure 3. Green construction techniques can be integrated into BMPs for small structures used to store field equipment or to house treatment components such as pump equipment.*

## ■ *Site Investigations and Monitoring*

Green remediation builds additional sustainability into practices already used for site evaluations and encourages development of novel techniques. Removal actions as well as site assessments and investigations should maximize opportunities for combining field activities in ways that reduce waste generation, conserve energy, and minimize land and ecosystem disturbance. Site investigation and monitoring, including well placement, should consider land reuse plans, local zoning, and maintenance and monitoring of any engineering and institutional controls. BMPs of green remediation help identify sustainable approaches for field work commonly involving subsurface drilling and multimedia data gathering.

At Superfund sites, for example, sampling and analysis plans are required to contain an investigation derived waste (IDW) plan that describes how all ARARS for waste generation and handling will be met, and the best approach for minimizing waste generation, handling, and disposal costs. IDW requirements also apply to projects involving offsite disposal of hazardous waste under other cleanup programs such as RCRA. Typical IDW includes:

- Drilling fluids, cuttings, and purge water from test pits and well installations,
- Purge water, excess soil, and other materials from sample collection,
- Residues such as ash, spent carbon, and well purge water from testing of treatment technologies and aquifer pumping tests,
- Contaminated personal protective equipment, and
- Solutions used to decontaminate non-disposable protective clothing and equipment. [19, 20]

Personal protective equipment is usually changed on a daily basis; fewer days in the field result in a smaller quantity of contaminated equipment needing disposal. When cleaning field equipment such as soil and water samplers, drill rods, and augers to prevent contaminant transfer between sample locations, consider using steam and non-phosphate detergent instead of toxic cleaning fluids. Organic solvents and acid solutions should be avoided in decontamination procedures but may be required when addressing free-product contaminants or high concentrations of metals.

Where technically feasible, collection of subsurface soil and ground water samples can rely on direct push drilling rigs rather than conventional rotary rigs. Direct push techniques employ more time-saving tools (particularly for subsurface investigations extending less than 100 feet below ground surface), avoid use of drilling fluids, and generate no drill cuttings. Total drilling duration is estimated to be 50-60% shorter for direct push systems. In addition, direct push rigs can be used to collect soil and ground water samples simultaneous to the drilling process. This approach results in reduced IDW volume and field mobilization with related fuel consumption and site disturbance.

Larger push rods now available on the market enable a direct push rig to be used also for placement of monitoring wells with pre-packed screen sizes. This approach provides an alternative to the conventional, energy intensive method involving use of a direct push rig to determine only the location of a long-term monitoring well, and subsequent placement of the well through use of an auger rig. Although some states have not approved wells placed through direct push techniques, this approach to monitoring well installation provides additional fuel and waste savings and significantly reduces the extent of site disturbance. Regardless of drill technique, many rigs operate with diesel engines that can use biodiesel fuel. Site investigations should avoid use of oversized equipment and unnecessary engine idling to maximize fuel conservation.

Geophysical techniques such as ground penetrating radar could be used at some sites to reduce the need for direct measurement of stratigraphic units. Feasibility of using geophysical methods for these purposes depends heavily on site conditions and the nature of contamination. Geophysical surveys result in much smaller environmental footprints than invasive techniques for site investigations, including cone penetrometer test rigs.

BMPs include use of passive sampling techniques for monitoring quality of air, sediment, and ground or surface water over time. In contrast to traditional methods involving infrequent and invasive spot-checking, these methods provide for steady data collection at less cost while generating less waste. Passive techniques for water sampling rely on ambient flow-through in a well without well pumping or purging, avoiding the need for disposal of large volumes of water that require management as hazardous waste. For some contaminants, however, passive devices for obtaining ground water samples are ineffective. [21]

Remote data collection significantly reduces onsite field work and associated labor cost, fuel consumption, and vehicular emissions. For example, water quality data on streams in acid mine drainage areas can be monitored automatically and transmitted to project offices through solar powered telemetry systems. This approach can be used for site investigations as well as site monitoring once treatment is initiated. Renewable energy powered systems with battery backup can be used to operate meteorological stations, air emission sensors, and mobile laboratory equipment. Remote systems also provide quick data access in the event of treatment system breakdown.

Green remediation builds on methods used in the Triad decision-making approach to site cleanup: systematic planning, dynamic work strategies, and real-time measurement systems. The approach advocates onsite testing of samples with submission of fewer samples to offsite laboratories for confirmation. The need for less offsite confirmation saves resources otherwise spent in preserving, packing, and shipping samples overnight to a laboratory. The number of required field samples also can be lowered through comprehensive review of historical information. The Triad approach allows for intelligent decision-making regarding the location and extent of future sampling activities based on the results of completed analytical sampling. This dynamic work strategy significantly minimizes unnecessary analytical sampling. [22]

## ■ *Air Quality Protection*

Green remediation strategies for air quality protection build on requirements or standards under the Clean Air Act, Energy Policy Act, and Energy Independence and Security Act. Cleanup at many sites involves air emissions from treatment processes and often requires use of heavy diesel-fueled machinery such as loaders, trucks, and backhoes to install and sometimes modify cleanup systems (Table 1). BMPs for operation of heavy equipment as well as routine on- or off-road vehicles provide opportunities to reduce emission of GHG and criteria pollutants such as sulfur dioxide. These practices encourage use of new user-friendly tools becoming available from government agencies and industry to help managers estimate and track project emissions.

*Contracts for field service can include specifications regarding diesel emissions and air quality controls. Sample language may be drawn from EPA's Clean Construction USA online resource. [23]*

Overall efforts should be made to minimize use of heavy equipment and to operate heavy equipment and service vehicles efficiently. Site contracts for service vendors or equipment should give preference to providers able to take advantage of air protection opportunities:

- Retrofitting machinery for diesel-engine emission control and exhaust treatment technologies such as particulate filters and oxidation catalysts,
- Maintaining engines of service vehicles in accordance with manufacturer recommendations involving air filter change, engine timing, and fuel injectors or pumps,
- Refueling with cleaner fuels such as ultra-low sulfur diesel,
- Modifying field operations through combined activity schedules as well as reducing equipment idle, and
- Replacing conventional engines of existing vehicles when feasible, and purchasing new vehicles that are equipped to operate on hybrid systems or alternative fuel and meet the latest engine standards. [24, 25]

Table 1. Mobile sources typically employed during a five-year multi-phase extraction treatment project could consume nearly 30,000 gallons of fuel, equivalent to the amount of carbon annually sequestered by 62 acres of pine or fir forests. [26]

| Field Machinery and Vehicles Used for a Typical Multi-Phase Extraction Project | Fuel Consumption (gallons) | $CO_2$ Emission (pounds) |
|---|---|---|
| Site Preparation: One Bobcat with intermittent use of flatbed trailer-truck or dump truck operating for 26 weeks | 8,996 | 199,711 |
| Well Construction: Truck-mounted auger system installing ten 75-foot extraction wells over 30 days | 612 | 13,586 |
| Routine Field Work: Two pickup trucks for site preparation, construction, treatment system monitoring, sampling, and repair over five-year duration | 19,760 | 383,344 |
| Total for Project Life: | 29,368 | 596,641 |

Site management plans should specify procedures for minimizing worker and community exposure to emissions, and for minimizing fuel consumption or otherwise securing alternatives to petroleum-based fuel. Plans also should contain specific methods to avoid dust export of contaminants, such as using simple wet-spray techniques, and to control noise from power generation.

## ■ *Water Quality Protection and Conservation*

Best practices for stormwater management limit the disruption of natural water hydrology by reducing impervious cover, increasing onsite infiltration, and reducing or eliminating pollution from stormwater runoff. Green goals used in industry-based programs such as LEED can be applied to cleanup construction; sample targets include:

- Implementing a management plan that results in a 25% decrease in runoff at sites with impervious cover exceeding 50%,
- Capturing 90% of the site's average annual rainfall, and
- Removing 80% of the average annual total load of suspended solids based on pre-construction monitoring reports.

*Site "fingerprinting" is an ecology-based planning tool focused on the protection of natural resources during site development.*

Site management plans can describe BMPs for reducing and controlling stormwater runoff in manners that mimic the area's natural hydrologic conditions, otherwise known as low impact development (LID). Cleanup at sites undergoing redevelopment could introduce best practices to be used during later stages:

- Conservation designs for minimizing runoff generation through open-space preservation methods such as cluster development, reduced pavement widths, shared transportation access, reduced property setbacks, and site fingerprinting during construction,
- Engineered structures or landscape features helping to capture and infiltrate runoff, such as basins or trenches, porous pavement, disconnected downspouts, and rain gardens or other vegetated treatment systems,
- Storage of captured runoff in rain barrels or cisterns, green (vegetated) roofs, and natural depressions such as landscape islands, and
- Conveyance systems to route excess runoff through and off the site, such as grassed swales or channels, terraces or check dams, and elimination of curbs and gutters. [27]

BMPs reflect maximum efforts to reclaim treated water for beneficial use or re-inject it into an aquifer for storage, rather than discharging to surface water. Where treatment processes result in wastewater discharge to surface water or municipal sewage treatment plants (publicly owned treatment works), green remediation strategies build on criteria of EPA's effluent guidelines. The guidelines rely on industry-proven performance of treatment and control technologies. Best practices for wastewater treatment, including any resulting in pollutant discharge significantly below regulatory thresholds, can be recorded in associated permits for national pollutant discharge elimination systems. [28]

Profile: Old Base Landfill, Former Naval Training Center-Bainbridge, Port Deposit, MD

*Cleanup Objectives:* *Contain an unlined landfill containing nearly 38,000 cubic yards of soil contaminated by waste such as pesticides and asbestos debris*

*Green Remediation Strategy:* *Employed BMPs for controlling stormwater runoff and sediment erosion during construction of a landfill cover*
- *Installed a woven geotextile silt fence downgradient of construction to filter sediment from surface runoff*
- *Added a "super-silt fence" (woven geotextile with chain-link fence backing) on steep grades surrounding the landfill*
- *Constructed berms and surface channels to divert stormwater to sediment ponds*
- *Emplaced erosion control blankets to stabilize slopes and channels until vegetation was established*
- *Hydroseeded the landfill cover with native seed to foster rapid plant growth*

*Results:*
- *Effectively captured sediment at super-silt fence despite heavy rain of Hurricane Floyd*
- *Avoided damage of infrastructure used in site redevelopment*
- *Reestablished 100% vegetative cover within one year*

*Property End Use:* *Redevelopment for office and light industrial space*

BMPs could include estimates of the anticipated demands for potable and non-potable water and substitution of potable with non-potable water whenever possible. One goal might be to replace 50% of the potable water used at a site with non-potable water. Targets can be met by using high efficiency water fixtures, valves, and piping, and by reusing stormwater and greywater for applications such as mechanical systems and custodial operations.

Green remediation practices potentially help cleanups not only meet but exceed water-quality and drinking-water standards set by federal and state agencies. In turn, the benefit of higher water quality can be passed to future site users. Broader strategies for managing a cleanup project's impact on local watershed conditions can complement regional water and waste programs for watershed restoration. [29]

## ■ *Ecological and Soil Preservation*

Green remediation practices provide a whole-site approach that accelerates reuse of degraded land while preserving wildlife habitat and enhancing biodiversity. BMPs can provide novel tools for measuring a site's progress toward meeting both short- and long-term ecological land reuse goals involving:

- Increased wildlife habitat,
- Increased carbon sequestration,
- Reduced wind and water erosion,
- Protection of water resources,
- Establishment of new greenspaces or corridors,
- Increases in surrounding property values, and
- Improved community perception of a site during cleanup. [30]

Site management plans can describe an approach to ecological preservation that considers anticipated reuse as well as the natural conditions prevailing before contamination occurred. BMPs address daily routines that minimize wildlife disturbance, including noise and lights affecting sensitive species. On previously developed or graded sites, goals for habitat restoration might include planting of native vegetation on 50% of the site. Native plants require minimal or no irrigation following establishment and require no maintenance such as mowing or chemical inputs such as fertilizers. Invasive plants or noxious weeds are always prohibited.

Profile: California Gulch Superfund Site, Leadville, CO

*Cleanup Objectives:* *Address metals-contaminated soil at a former mining site*

*Green Remediation Strategy:* *Constructed a recreational trail serving as a cap for contaminated soil*

- *Conducted a risk-based assessment to confirm trail interception of exposure pathways for waste left in place*
- *Demonstrated the trail would not harm adjacent wetlands and streams*
- *Completed a cultural resource inventory and mitigation plan to meet historic preservation requirements*
- *Consolidated slag-contaminated soil into a platform running along the site's former rail and haul-road corridor*
- *Covered the soil platform with a six-inch layer of gravel spanning a width of 12 feet with additional three-foot shoulders*
- *Installed six inches of asphalt above the gravel layer*

*Results:*

- *Avoided invasive soil excavation and costly offsite disposal*
- *Reduced consumption and cost of imported construction material through use of contained waste-in-place*
- *Increased user safety and remedy integrity through trail restriction to non-motorized use*
- *Relied on an integrated remediation and reuse plan involving extensive community input, donation of land and construction material by the property owner, and long-term trail and remedy maintenance by Lake County, CO*

*Property End Use:* *Recreation*

Ecological restoration and preservation at sites anticipated for full or partial reuse as greenspace are best managed through site surveys and careful master planning. BMPs for greenspace could include targets such as confining site disturbance to areas within 15 feet of roadways and utility trenches or within 25 feet of pervious areas of paving.

BMPs include development of an erosion and sedimentation control plan for all activities associated with cleanup construction and implementation. Objectives include:

- Preventing loss of soil by stormwater runoff or wind erosion,
- Preventing topsoil compaction, thereby increasing subsurface water infiltration,
- Preventing sediment transport to storm sewers or streams, and
- Preventing dispersion of dust and particulate matter.

Potential strategies for erosion and sedimentation control include stockpiling of topsoil for reuse, temporary and permanent seeding, mulching, earth dikes, silt fencing, straw-bale barriers, sediment basins, and mesh sheeting for ground cover.

## ■ *Waste Management*

Green remediation practices for waste management encourage consumers to consider lifecycle cost (including natural resource consumption) of products and materials used for remedial activities. BMPs build on requirements set by municipal or state agencies and those formalized in various construction and operating permits. A site management plan should include waste planning practices that apply to all cleanup and support activities. For sites involving construction and demolition or requiring diversion of landfill waste, stakeholder collaboration plays a significant role in sustainable cleanup.

Profile: Rhizome Collective Inc. Brownfield Site, Austin, TX

*Cleanup Objectives:* *Clean up illegal dump containing 5,000 cubic yards of debris*

*Green Remediation Strategy:* *Constructed a four-foot-thick evapotranspiration cover*

- *Salvaged wood scraps and concrete for erosion control*
- *Chipped or shredded wood to create mulch for recreational trails*
- *Recycled 31.6 tons of metal*
- *Salvaged concrete for later use as fill for building infrastructure*
- *Powered equipment through use of biofuel generators and photovoltaic panels, due to lack of grid electricity*
- *Extracted 680 tires through use of vegetable oil powered tractor*
- *Inoculated chainsaws with fungi spore-laden oil to aid in degradation of residual contaminants*
- *Constructed floating islands of recovered plastic to create habitat for life forms capable of bioremediating residual toxins in an onsite retention pond*
- *Planted native grasses, wildflowers, and trees*

*Results:*

- *Reestablished wildlife habitat for native and endangered species*
- *Gained community help to restore the property within a single year*

*Property End Use:* *Environmental education park*

BMPs for waste management during site cleanup are borrowed from the construction industry. Demolition concrete, for example, is often re-used onsite as road base, fill, or other engineering material. Reducing and recycling debris such as concrete, wood, asphalt, gypsum, and metals helps to:

- Conserve landfill space,
- Reduce the environmental impact and cost of producing new materials, and
- Reduce overall project expenses through avoided purchase and disposal costs.

Waste management practices should consider every opportunity to recycle land-clearing debris, cardboard, metal, brick, concrete, plastic, clean wood, glass, gypsum wallboard, carpet, and insulation. Site preparation can include early confirmations with commercial haulers, deconstruction specialists, and recyclers. A convenient and suitably sized area should be designated onsite for recyclable collection and storage. Requirements for worker use of cardboard bailers, aluminum can crushers, recycling chutes, and sorting bins will facilitate the waste management program. In addition, stakeholders can help identify local options for material salvage that may include donation of materials to charitable organizations such as Habitat for Humanity. To document BMPs, site managers are encouraged to track the quantities of waste that are diverted from landfills during remediation.

Investigation derived waste such as drilling fluids, spent carbon, and contaminated personal protection equipment must be appropriately contained and stored outside of general recycling or disposal areas. Preference should be given to building- and equipment-cleaning supplies with low phosphate and non-toxic content.

*Green waste management practices rely on recycling, reusing, and reclaiming materials to the greatest extent possible. [31]*

# Section 4: Energy and Efficiency Considerations

Energy requirements constitute a core element of green remediation. Significant reductions in fossil fuel consumption during treatment processes can be achieved through (1) greater efforts to optimize treatment systems, and (2) use of alternative energy derived from natural, renewable energy sources. "Active energy" systems use external energy to power mechanical equipment or otherwise treat contaminated media. These systems typically consume high quantities of electricity, and to a lesser extent natural gas, although duration of peak consumption varies among cleanup technologies and application sites. In 2007, approximately 70% of the U.S. electricity supply was generated by fossil fuel-fired plants.

$CO_2$ is one of several gases with potential to contribute to climate change. $CO_2$ is produced from a variety of sources including fossil fuel combustion and industrial process emissions. Electric power production is the largest source of $CO_2$ emissions in the U.S. energy sector, representing approximately one-third of the total.

EPA's Office of Solid Waste and Emergency Response (OSWER) is analyzing the extent of energy use, $CO_2$ emissions, and energy cost of technologies used to treat contaminated media at NPL sites. The analysis will help the Agency to:

- Establish benchmarks regarding the energy consumption of technologies with high energy demand,
- Examine operational and management practices typically used to implement these technologies, and
- Identify methods for reducing energy consumption during treatment processes and optimizing the systems.

The most frequently used energy-intensive treatment technologies used at NPL sites are pump-and-treat (P&T), thermal desorption, multi-phase extraction, air sparging, and soil vapor extraction (SVE). Using data from cost and performance reports compiled by the Federal Remediation Technologies Roundtable and other resources, OSWER estimates that a total of more than 14 billion kilowatt-hours (kWh) of electricity will be consumed through use of these five technologies at NPL sites from 2008 through 2030 (Table 2).

*Table 2. Technologies used for Superfund cleanups often involve energy intensive components such as ground water extraction pumps, air blowers, or ultraviolet lamps (U.S. EPA/OSWER, 2008(b).*

| Technology | Estimated Energy Annual Average ($kWh*10^3$) | Total Estimated Energy Use in 2008-2030 ($kWh*10^3$) |
|---|---|---|
| Pump & Treat | 489,607 | 11,260,969 |
| Thermal Desorption | 92,919 | 2,137,126 |
| Multi-Phase Extraction | 18,679 | 429,625 |
| Air Sparging | 10,156 | 233,599 |
| Soil Vapor Extraction | 6,734 | 154,890 |
| *Technology Total* | *618,095* | *14,216,209* |

DOE estimates that 1.37 pounds of $CO_2$ are emitted into the air for each kWh of electricity generated in the United States. Accordingly, use of these five technologies at NPL sites in 2008 through 2030 is anticipated to indirectly result in $CO_2$ emissions totaling nearly 9.2 million metric tons (Table 3) (U.S. EPA/OSWER, 2008(b)).

Based on the average electricity cost of $0.0914/kWh in December 2007, consumption of fossil fuel energy at NPL sites during operation of these five technologies is anticipated to cost over $1.4 billion from 2008 through 2030. Use of these technologies under other cleanup programs such as RCRA, UST, or brownfields could produce similar results. Trends in the use of active energy treatment systems often vary among the various cleanup programs due to the type and extent of contamination and cleanup practices commonly encountered within each program.

*Table 3. Estimated $CO_2$ emissions from use of five types of cleanup technologies at NPL sites over 23 years are equivalent to operating two coal-fired power plants for one year. [26]*

| Technology | Estimated $CO_2$ Emissions Annual Average (Metric Tons) | Total Estimated $CO_2$ Emissions in 2008-2030 (Metric Tons) |
|---|---|---|
| Pump & Treat | 323,456 | 7,439,480 |
| Thermal Desorption | 57,756 | 1,328,389 |
| Multi-Phase Extraction | 12,000 | 276,004 |
| Air Sparging | 6,499 | 149,476 |
| Soil Vapor Extraction | 4,700 | 108,094 |
| *Technology Total* | *404,411* | *9,301,443* |

General assumptions used in these estimates are dependent on and sensitive to factors such as site size or setting. The estimates do not include variable demands of additional electricity consumed during site investigations, field trials, remedy construction, treatment monitoring, and other activities. The Agency's online *Power Profiler* can help estimate air emissions attributable to electricity consumption at specific sites based on geographic power grids. [32]

## ■ Optimizing Energy Intensive Systems

Significant reductions in natural resource and energy consumption can be made through frequent evaluation of treatment system efficiencies before and during operations. Opportunities to optimize systems and integrate high performance equipment begin during feasibility studies, when potential remedies are evaluated and the most appropriate and cost-effective cleanup technology is selected. In accordance with green remediation strategies, feasibility studies could include comparison of the environmental footprint expected from each cleanup alternative, including GHG emissions, carbon sequestration capability, and water drawdown (lowering of the water table or surface water levels).

The subsequent design phase involves planning of the selected technology's engineering aspects such as equipment sizing and integration. Energy consumption of remediation technologies ranges considerably, from soil excavation that requires virtually no mechanical integration or electrical power, to treatment trains involving media extraction and aboveground exposure to a series of electrically driven physical or chemical processes. In contrast to a "bottom up" approach, most cleanup technologies are designed through a series of equipment specifications requiring adjustment when components are integrated. Project solicitations for equipment and services should contain specifications regarding product efficiency, reliability, fuel consumption, air emissions, water consumption, and material content.

*Selection of equipment and service providers must meet a project's performance and cost requirements, giving preference to products and user techniques working together to reduce environmental footprints.*

Equipment and vendor selection can maximize use of alternative fuel and renewable energy sources. Where alternatives are currently unavailable or infeasible, designs can document the project's baseline energy demand for future reconsideration. Energy efficiency can be gained relatively simply by techniques such as insulating structural housing and equipment used to maintain certain process temperatures; installing energy recovery ventilators to maintain air quality without heat or cooling loss in treatment buildings; and weather-proofing system components that are exposed to outside elements. Electronic data systems for controlling and monitoring operations also provide significant opportunity to conserve energy, particularly in the multi-step processes commonly used for P&T. EERE has identified specific opportunities to identify and quantify energy efficiencies that might occur during pumping operations. Inefficiency symptoms include use of throttle-valve controls, cavitation noise or damage, continuous pumping to support a batch process, open bypass or recirculation lines, and functional changes of a system. [33]

Treatment system designs also should compare the environmental footprint left by alternate methods of managing process water, whether through re-injection to an aquifer, discharge to surface water, or pumping to a publicly owned wastewater treatment plant. Effective designs maximize every opportunity to recycle process fluid, byproducts, and water; reclaim material with resale value; and conserve water through techniques such as installation of automatic shut-off valves. To reduce impacts on water quality, construction designs can follow LID practices helping to infiltrate, evapotranspire, and re-use stormwater runoff in ways mirroring the site's natural hydrology.

Green remediation relies on maximizing efficiencies and reducing natural resource consumption throughout the duration of treatment. Upon process startup, tests are conducted to ensure the system is functioning as designed. For a technology such as *in situ* chemical oxidation, testing primarily involves ensuring that an injected material is reaching the target treatment zone. For a complex multi-contaminant P&T system, however, numerous tests are conducted to ensure that flow rates for each process step are appropriate and that equipment is properly sized.

Remedial system evaluations (RSEs) provide examples of BMPs already in place. EPA is conducting RSEs for operating P&T systems at Superfund-lead sites to:

- Indicate whether the original monitoring or treatment system design is fully capturing the target contaminant plume,
- Determine whether new monitoring or extraction wells are needed,
- Recommend specific modifications to increase system performance and efficiency, and
- Obtain cost savings from direct optimization or project management improvements. [34]

RSEs often find that energy intensive equipment such as pumps and blowers are oversized or set at operating rates or temperatures higher than needed, resulting in excess energy consumption (U.S. EPA/OSWER, 2002). Evaluations such as these also help to remove redundant or unnecessary steps in a treatment process, consider alternate discharge or disposal options for treated water or process waste, and eliminate excess process monitoring.

Standard operating procedures for treatment systems should include frequent reconsideration of opportunities to increase operational efficiencies. System optimization should carry forward to long-term operation and maintenance (O&M) programs that ensure system components are performing as designed. Poorly operating or broken equipment should be repaired immediately to avoid treatment disruption and energy waste.

Subsurface remediation generally changes dynamics of the natural system as well as distribution of contaminants. Changes might occur slowly, not becoming evident for several years. Periodic RSE helps to identify any subsurface changes, prompting modification to long-term treatment operations. Many years of P&T operations, for example, could change dynamics of plume behavior to the point where an outside extraction well that originally pumped contaminated water is later capturing clean water. In this case, shutdown of the extraction well will result in significant energy and cost savings.

Most remedies for soil and sediment (*in situ* oxidation, thermal treatment, and solidification/stabilization) are short-term in nature but require continual optimization throughout operations. Optimization of a biological system ensures that geochemical conditions such as reduction/oxidation, electron donor availability, and oxygen content are maximized.

In contrast to other soil and sediment technologies, SVE treatment results in contaminant loading that is initially high but decreases over time, prompting the need for frequent system modifications. Key opportunities for SVE optimization include (1) determining if any well in a manifold system is not contributing contaminants, and if so, taking the well offline, (2) operating pulsed pumping during off-peak hours of electrical demand, as long as cleanup progress is not compromised, and (3) considering alternative technologies with lower cost and energy intensity once the bulk of contamination is removed. The EPA, U.S. Air Force Center for Engineering and the Environment, Federal Remediation Technologies Roundtable, and Interstate Technology and Regulatory Council continue to develop tools such as checklists and case studies to help project managers optimize cleanup systems for all environmental media. [35-38]

Profile: Havertown PCP Site, Havertown, PA

*Cleanup Objectives: Remediate shallow ground water containing metals, chlorinated volatile organic compounds (VOCs), benzene, and dioxins/furans*

*Green Remediation Strategy:* Conducted *RSE evaluation of a 12-acre treatment area encompassing*
- *Four recovery wells*
- *One collection trench*
- *A pre-treatment system to break oil/water emulsion, remove metals, and remove suspended solids in extracted ground water*
- *An aboveground system employing three 30-kW ultraviolet/oxidation (UV/OX) lamps, a peroxide destruction unit, and two granular activated carbon units to destroy or remove organic contaminants*

*Results:*
- *Removed two UV/OX lamps from the treatment line, based on RSE recommendations*
- *Reduced annual operating costs by $32,000, primarily due to lower electricity consumption*
- *Continues to meet cleanup criteria for ground water*

*Property End Use: Undetermined*

## ■ *Integrating Renewable Energy Sources*

Incorporation of alternative, renewable energy sources into site cleanup may reduce a project's carbon footprint while offering other benefits:

- Hedge against fossil fuel prices, with the potential for near- and long-term cost savings,
- Lower demand on traditional energy sources,
- Reduced need for emission controls related to onsite fossil fuel consumption, and
- Opportunities for new energy markets and job creation when combined with site revitalization.

Renewable energy sources can be used to meet partial or full demand of a treatment system. When meeting partial demand, a renewable energy system can be designed to power one or more specific mechanical components or to generally supplement grid electricity supplied to the entire treatment process. EPA's *Green Power Equivalency Calculator could* be used to better understand and communicate the environmental benefits of directly or indirectly using electricity produced from solar, wind, geothermal, biogas, biomass, and low-impact small hydroelectric sources, otherwise known as "green power." [39]

Energy alternatives already available for remediation and revitalization include solar, wind, landfill gas, and waste-to-energy sources. Emerging technologies such as geothermal and tidal power also could be used for site-wide applications or as means to optimize treatment system components. Potential integration of renewable energy sources considers:

- Natural resource availability, reliability, and seasonal variability,
- Total energy demand of the treatment system,
- Proximity to utility grids, and associated cost and time needed to connect to the grid,
- Back-up energy sources for treatment or safety,
- Cost tradeoffs associated with cleanup duration and economy of scale, and
- Long-term viability and potential reuse.

*Renewable energy industries estimate a current renewable energy capacity of 550-770 gigawatts in the United States, with growth sufficient to meet at least 25% of the country's electricity needs by 2025. (ACORE/ABA, 2008)*

Renewable energy provides significant opportunities at sites that require long-term treatment, are located in remote areas, or involve energy intensive technologies such as P&T. Renewable energy systems can operate independently without connection to a utility grid (off-grid) or as interconnected systems tied to the utility power grid (inter-tie). Energy management tools can be used to monitor supply and demand, automatically shutting off or initiating grid power as desired. Hybrid systems combining capability of two or more renewable resources often provide the most efficient and cost-effective option in rural areas or to achieve total energy independence.

Off-grid systems are best suited to mechanical or infrastructure components with low or intermittent energy demands such as small pumps, communication systems, or the interior of small buildings. Cost effectiveness of off-grid systems significantly increases at remote sites, where extension of utility lines might be cost prohibitive or otherwise infeasible due to difficult access. As in all optimized engineering systems, effective renewable energy systems include climate control measures to minimize energy loss throughout the mechanical network.

Interconnection of renewable energy systems with the utility grid allows use of utility power when availability of a natural resource is low, without disruption to site cleanup operations. Excess energy produced by a small renewable energy system could be stored in batteries until needed or transferred to the grid for consumption by other users. Most states now require electric utilities to offer net metering, a service that enables renewable energy generators to receive utility consumption credit. The amount of excess electricity transferred to the grid could be directly measured through installation of an additional meter or generally monitored through visual observation of the primary utility meter "spinning backward." DOE's National Renewable Energy Laboratory (NREL) is working with other government agencies and private industry to develop consistent standards for grid interconnection, system engineering, and power production market rules.

Capital costs for renewable energy systems continue to decrease as technologies advance and as demand steadily increases but might prohibit their use in some projects. Costs can be lowered by taking advantage of federal and state rebates or tax credits or shared through reuse of equipment in other cleanup projects. Project decision-makers are encouraged to capitalize on 10-year renewable energy incentives now available to help capture long-term savings while strengthening community economics.

Increasing numbers of regional partnerships are forming to help property owners install large utility-grade systems that can meet energy demands of onsite operations such as remediation, while receiving production tax credit and allowing sale of excess energy to the utility at wholesale price. Another mechanism is the power purchase agreement, which enables owners of large properties to lease land to a utility for installation and operation of a renewable energy network (typically solar or wind systems) while purchasing electricity at a considerably lower rate. These partnerships add to renewable energy portfolios maintained by state agencies and authorized utilities to help meet national goals. Accordingly, new generators of renewable energy are actively solicited by states working to meet the goals of renewable portfolios. [40]

Profile: Former St. Croix Alumina Plant, St. Croix, VI

*Cleanup Objectives: Recover hydrocarbons from ground water at a RCRA site*

*Green Remediation Strategy: Uses a hybrid system employing solar and wind energy*

- *Began operating four wind-driven turbine compressors in 2002 to drive compressed air into hydraulic skimming pumps*
- *Installed three 55-watt photovoltaic panels in 2003 to power some recovery wells*
- *Added three 110-watt photovoltaic panels and two wind-driven electric generators in 2006 to power a total of nine submersible total-fluid pumps and the fluid-gathering system*
- *Recycles recovered petroleum product by transfer to an adjacent oil refinery for use as feed stock*

*Results:*

- *Recovered 228,000 gallons of free-product oil (approximately 20% of the estimated volume) by the end of 2006*
- *Avoids offsite transfer and disposal of petroleum product*

*Property End Use: Industrial operations*

(U.S. EPA/OSWER, 2008(c))

## Solar Energy

Solar energy can be used in site cleanups through one or more methods involving photovoltaics (PV), direct or indirect heating and lighting systems, or concentrating solar power. PV technology easily lends itself to applications involving remote locations, a need for portability, or support for long-term treatment systems. This technology is already in place or under design at numerous sites.

PV cells consist of absorbing, semiconducting material that converts sunlight directly into electricity. Typically, about 40 PV cells are combined to form a module, or panel. Approximately ten of the modules are combined on a flat-plate PV array that might range several yards in size. An array could be mounted at a fixed angle facing south, or on a tracking device following the sun to allow maximum capture of sunlight over the course of a day. Six to 12 modules might meet all or part of a treatment system with low energy demand. In contrast, 10-20 arrays could be needed to power systems on the order of a small industrial facility or hundreds of arrays can be interconnected to form a single system.

Use of solar energy at the Pemaco Superfund site in Maywood, CA, demonstrates the flexibility and capability of solar technology in helping to meet energy demands of above-ground treatment operations. Four PV panels with a total generating capacity of 3 kW were installed on the existing building, which houses a soil and ground water treatment system employing high-vacuum pumps, controls for electrical resistance heating, a granular activated carbon unit, and a high-temperature flameless thermal oxidizer. The PV system contributes a total of 375 kWh of electricity to the building operations each month, avoiding more than 4,300 pounds of $CO_2$ emissions per year. After the first nine months of operation, solar energy had generated enough power to cover one month of the building's electricity expenses for system controls and routine operations. Payback for PV capital costs is estimated at one year.

Profile: BP Paulsboro, Paulsboro, NJ

*Cleanup Objectives: Remove petroleum products and chlorinated compounds from surface and ground water near a Delaware River port*

*Green Remediation Strategy: Uses a solar field to power P&T system extracting 300 gallons of ground water per minute*
- *Installed a 275-kW solar field encompassing 5,880 PV panels in 2003*
- *Uses solar energy to operate six recovery wells including pump motors, aerators, and blowers*
- *Transfers extracted ground water into a biologically activated carbon treatment system*

*Results:*
- *Supplies 350,000 kWh of electricity each year, meeting 20-25% of the P&T system energy demand*
- *Eliminates 571,000 pounds of $CO_2$ emissions annually, equivalent to avoiding consumption of 29,399 gallons of gasoline*
- *Prevents emission of 1,600 pounds of sulfur dioxide and 1,100 pounds of nitrogen dioxide each year*
- *Provides opportunity for reuse and expansion of the PV system, with potential capital cost recovery if integrated into site reuse*

*Property End Use:* Port operations

(U.S. EPA/OSWER, 2007(a))

Aboveground treatment processes also can use solar thermal methods. These methods employ solar collectors such as engineered panels or tromb walls to absorb the sun's energy, providing low-temperature heat used directly for space heating.  In contrast, solar water heaters use the sun to directly heat water or a heat-transfer fluid in collectors.  Industrial-grade solar heaters can be used to provide hot water and hot-water heat for large treatment facilities.

Passive (non-mechanical) methods also could be used to heat treatment buildings, potentially reducing structural energy consumption by up to 50%.  Buildings can be designed to include large spans of windows with southern exposure or constructed of materials with high mass value (high absorbency but slow heat release).  Passive solar designs also include natural ventilation for cooling.  Daylighting of treatment buildings can be enhanced through installation of conventional skylights or smaller "tubular skylights" constructed of reflective material.  Also, parabolic solar collectors could be used to supplement electricity demands of fiber optic systems for treatment monitoring or data transfer.

The potential for using active or passive solar energy to meet the energy demands of treatment processes throughout the year can be calculated using the site's estimated insolation.  An insolation value indicates the rate at which solar radiation is delivered to a unit of horizontal surface.  Insolation values indicate radiation reflection or absorption by (1) flat-plate collectors facing south at fixed tilt (Figure 4), (2) single-axis (north/south) flat-plate collectors tracking from east to west, (3) two-axis flat-plate collectors tracking the sun in both azimuth and elevation, or (4) concentrating collectors using multiple axes to track direct solar beams.  Technical assistance and more information is available from NREL and the American Solar Energy Society to help site managers determine whether the energy demands of site remediation as well as anticipated reuse could be met by solar resources. [41, 42]

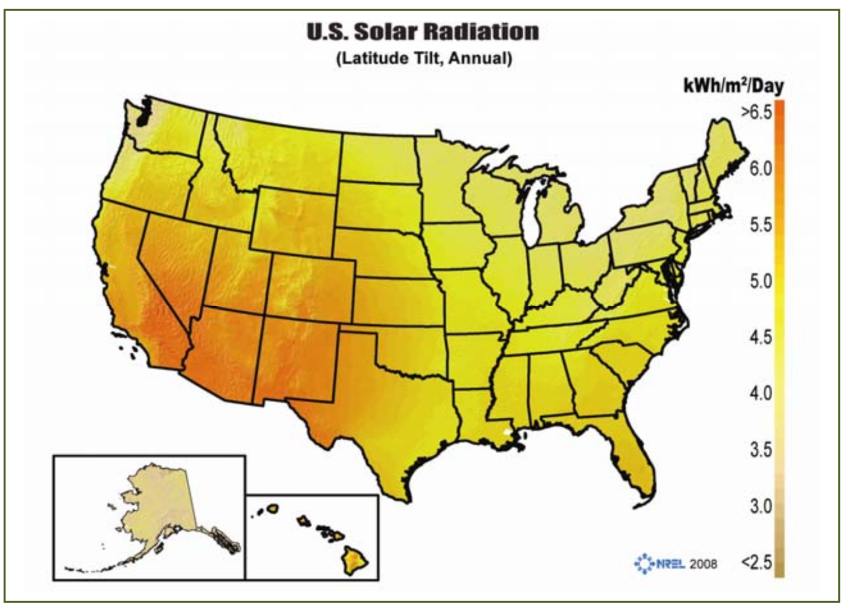


*Figure 4.  Estimates of U.S. annual solar resources indicate highest potential in the Southwest; in areas with lowest potential, resources remain equivalent to those of Germany, where solar energy is used routinely across business sectors. (U.S. DOE NREL, 2008(a))*

Concentrating solar power (CSP) systems provide significant opportunities at large sites undergoing cleanup and revitalization.  CSP systems use reflective materials such as mirrors or parabolic troughs to concentrate thermal energy driving an electricity generator, or concentrated PV technology to directly provide electrical current.  Large-scale CSP systems are under consideration at sites in southwestern portions of the United States.

## Wind Energy

Determining the potential for using wind energy to meet energy demands of a cleanup requires a wind resource assessment. The assessment involves collection of climatic data from an onsite or local weather station over the course of one year, although DOE's wind resource data might be sufficient for small applications on relatively flat terrain. Wind speed is critical but wind shear and turbulence intensity also impact assessment results. Generally, the amount of power available by wind is proportional to the cube of wind speed; for example, a two-fold increase in wind speed increases the available power by a factor of eight. Wind energy is best suited to resource areas categorized as "Class 3" or higher on DOE's scale of 1-7 (Figure 5). [43]

*Wind Power Classification*

| | Resource Potential (annual) | Wind Speed (at 50 meters, miles/hour) |
|---|---|---|
| 1 | Poor | 0.0-12.5 |
| 2 | Marginal | 12.5-14.3 |
| 3 | Fair | 14.3-15.7 |
| 4 | Good | 15.7-16.8 |
| 5 | Excellent | 16.8-17.9 |
| 6 | Outstanding | 17.9-19.7 |
| 7 | Superb | >19.7 |

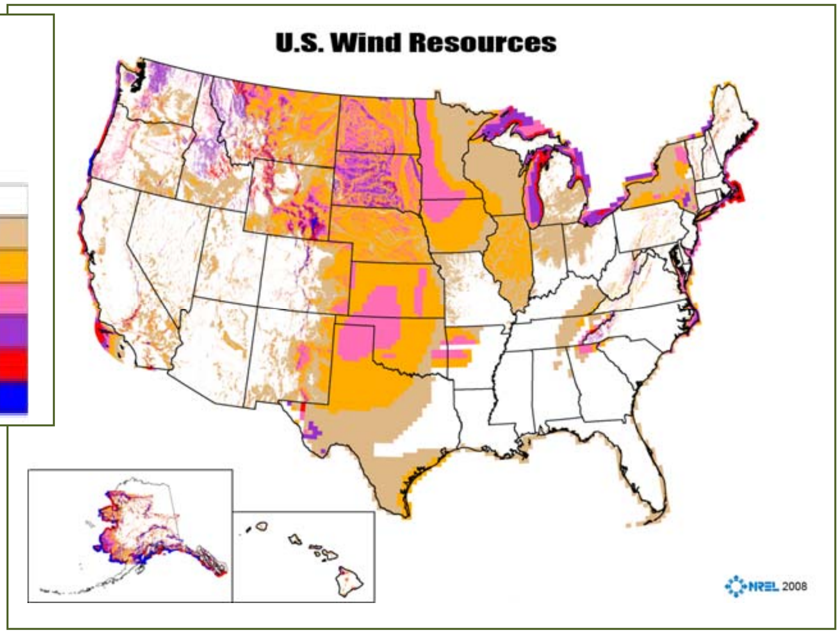


*Figure 5. NREL annual wind resource mapping shows excellent potential in portions of the Great Plains, and outstanding potential in coastal areas or at high altitudes common to many mining sites requiring cleanup and reuse (U.S. DOE/NREL, 2008(b)).*

Results of the wind resource assessment are compared to the cleanup's anticipated energy demand to determine whether wind energy would meet full or partial demand. Demands of low energy components such as small generators might be met by wind speeds of 6 miles per hour (mph), while activities such as ground water pumping generally require a wind speed above 9 mph. At sites with wind speeds averaging 12 mph, a small 10-kW wind turbine can generate approximately 10,000 kWh annually (equivalent to avoiding $CO_2$ emissions resulting from consumption of 882 gallons of gasoline).

In addition to wind speed, output of a wind turbine significantly depends on a turbine's size. Most small turbines consist of a rotor (encompassing the gearbox and blades) with diameters of less than 10 feet, mounted on towers 80-120 feet in height. Due to the low number of moving parts, most small turbines require little maintenance and carry an estimated lifespan of 20 years. Small systems cost $3,000-5,000 for every kilowatt of generating capacity, or approximately $40,000 for a 10-kW installed system.

Treatment systems requiring compressed air could be powered by wind-driven electric generators. This type of generator employs a small turbine or windmill to capture, compress, and direct air to equipment such as hydraulic pumps. The generator typically is designed to allow blade rollup and repositioning during excessive wind, and can easily be lowered to the ground for routine maintenance.

Increasing numbers of communities are examining opportunities for integrating renewable energy production into a contaminated site's long-term viability and reuse. Site revitalization involving production of electricity for utility distribution requires installation of co-located utility-scale (100-kW or more) turbines to form a wind farm (wind power plant). A wind farm is best suited to areas with wind speeds averaging at least 13 mph. A one-megawatt (MW) turbine can generate 2.4-3 million kWh annually; a 5-MW turbine can produce more than 15 million kWh annually. Capital and installation costs range according to factors including economy of scale and site-specific conditions such as terrain.

Integration of utility-scale energy production in site reuse considers efficiencies as well as economic factors. Commercial wind turbines average a mechanical and electric conversion efficiency of approximately 90%, and an aerodynamic efficiency of approximately 45%. In contrast, the average efficiency of electricity generating plants in the United States averages approximately 35%; over two-thirds of the input energy is wasted as heat into the environment.

Over the last 20 years, the cost of electricity from utility-scale wind systems has dropped more than 80%, from an earlier high of approximately 80 cents per kWh. With the use of production tax credits, modern wind power plants can generate electricity for 4-6 cents/kWh, which is competitive with the cost of new coal- or gas-fired power plants.

Profile: Former Nebraska Ordnance Plant, Mead, NE

*Cleanup Objectives:* *Remove trichloroethene and destroy explosives in ground water*

*Green Remediation Strategy:* *Uses a 10-kW wind turbine to power ground water circulation wells for air stripping and UV treatment*

- *Calculated a total demand of 767 kWh each month for the circulation wells*
- *Determined electricity demand could be met by site conditions including wind speed of 6.5 meters/second*

*Results:*

- *Provides sufficient energy for continued trichloroethene removal and explosives destruction by the aboveground treatment system during grid inter-tie operation*
- *Reduces consumption of utility electricity by 26% during grid inter-tie operation*
- *Decreases $CO_2$ emissions by 24-32% during off-grid operation of the system's 230-volt submersible pump*
- *Returns surplus electricity to the grid for other consumer use*
- *Results in no observable impacts on wildlife*
- *Provides electricity cost savings expected to total more than $40,000 over the next 15 years of treatment*
- *Estimated that cost recovery time for turbine capital and installation could be cut in half by improved freeze-proofing of wells*

*Property End Use:* *Continued agricultural research and development, residential, and commercial use*

(U.S. EPA/OSWER, 2007(b); University of Missouri-Rolla, 2005)

Design of a small wind system includes consideration of horsepower across the entire system to maximize efficiency. Ground water pumps, for example, typically operate at 50% efficiency, while turbine efficiency typically exceeds 90% and grid efficiency averages about 91% (U.S. DOE/EIA, 2007). Efficiency can be enhanced by grid interconnection allowing higher start-up current to be drawn from the grid and by avoiding the need for storage batteries.

Wind plants typically are designed in modules allowing for addition or subtraction of individual turbines as electricity demand changes. Construction of a 50-MW wind farm can be completed in six months, beyond the initial 12-18 months commonly needed for wind measurements and construction permits.

For maximum efficiency, installation locations should be sufficiently distant from trees or buildings that potentially reduce speed of wind entering the turbine. Selection of turbine sites also considers potential impacts on sensitive environments made by turbine noise (commonly compared to a domestic washing machine) and public perceptions regarding aesthetics of turbine sizes. A typical 100-kW turbine contains a rotor approximately 56 feet wide, while rotor width of a 1,650-kW turbine averages 233 feet. Height of a utility-scale tower ranges according to site conditions but generally is similar to rotor width.

EERE estimates wind energy is the fastest growing energy generation technology, expanding 30-40% annually. NREL and the American Wind Energy Association offer technical assistance on evaluating and implementing wind systems. [44]

## Landfill Gas Energy

Landfill gas (LFG) generated through decomposition of solid waste provides a potential source of energy at numerous sites across the country with abandoned or inactive landfills. LFG typically contains about 50% $CO_2$ and 50% $CH_4$. LFG-to-energy systems use extraction wells to capture gas before it enters the atmosphere or is burned as part of the landfill management process. Captured gas can be converted to an alternate fuel, to electricity for direct use, or to both electricity and thermal energy (co-generated heat and power, or CHP) for dedicated mechanical operations. [45]

Conversion of LFG to electricity is possible through a number of technologies, depending on the scale of generation. Proven technologies include microturbines, internal combustion engines, gas turbines, external combustion engines, organic Rankine cycle engines, and fuel cells. Microturbines range in power from 30 kW to 250 kW (not exceeding 1 MW), internal combustion engines range from 100 kW to 3 MW; and gas turbines range from 800 kW to 10.5 MW. Although combustion of LFG converts $CH_4$ to $CO_2$, the global warming potential of methane is 23 times higher than that of carbon dioxide. Increasing numbers of LFG applications involve development of aerobic digesters that rely exclusively on anaerobic bacteria to break down organic substances.

Effective design of an LFG energy system includes adequate conditioning that ensures converted gas is free of vapor and remaining contaminants or impurities, and operational practices that minimize liquid waste streams. Performance and lifespan of a system depend on long-term availability and reliability of the methane as an energy resource.

Profile: Operating Industries, Inc. Landfill, Monterey Park, CA

*Cleanup Objectives: Remediate soil and ground water contaminated by a 145-acre inactive landfill*

*Green Remediation Strategy: Convert LFG to electric power for onsite use*
- *Installed six 70-kW microturbines in 2002 as part of the LFG collection system*
- *Converts a LFG flow rate of 5,500 standard cubic feet per minute, with a $CH_4$ content of approximately 30%*
- *Returns microturbine emissions to the existing gas treatment system to ensure contaminant removal*

*Results:*
- *Generates sufficient energy to meet approximately 70% of onsite needs including thermal oxidation, a 40-horsepower gas blower, refrigeration units, and air-exchange systems*
- *Saves up to $400,000 each year in grid-supplied electricity expenses*

*Property End Use: Commercial/industrial operations or open space, pending Superfund close-out*

(U.S. EPA/OSWER, 2007(a))

LFG energy systems benefit from economy of scale. For example, EPA estimates that the total installed cost for an LFG microturbine project falls from $4,000-5,000 per kW for a small (30-kW) system to a cost of $2,000-2,500 per kW for systems rated 200 kW and higher. As of early 2007, 424 LFG energy projects operated in the United States, producing a total 1,195 MW of electricity. EPA estimates that an additional 560 landfills hold potential for converting LFG to productive use, with a total production potential of 1,370 MW of electricity. [46] This technology brings significant potential for reducing GHG emissions from landfills. The community of Shippensburg, PA, for example, anticipates that operation of its 6.4-MW LFG electricity-generating system will prevent emission of 39,000 tons of $CO_2$ each year (an equivalency of one coal-fired power plant generating electricity for nearly 660,000 homes).

## Waste-Derived Energy

Waste-to-energy (WTE) systems convert solid waste into electricity, or in some cases liquid waste to alternative fuel. Large sites undergoing remediation provide opportunities for local communities to consider reuse options involving WTE facilities as a means to:

- Reduce municipal landfill burdens posed by disposal of non-hazardous waste,
- Provide an alternative to onsite landfill construction,
- Procure a long-term source of renewable energy,
- Decrease export of waste from communities with little or no landfill capacity to other facilities, often in other states, and
- Provide employment opportunities.

An average municipal WTE facility emits 837 pounds of $CO_2$ per megawatt hour; in contrast, coal, oil, and natural gas facilities emit over 2,000, 1,600, and 1,100 pounds of $CO_2$ per megawatt hour, respectively (Solid Waste Association of North America, 2005; U.S. EPA, 2008 online). DOE's Energy Information Administration estimates that a total of 299 trillion British thermal units of energy were consumed by combustion of municipal solid waste in 2005 (U.S. DOE/EIA, 2008). Conversion of heat produced during this process is used increasingly to produce electricity. For example, Lee County, FL, recently expanded its existing 4 million-ton WTE combustion system to process an additional 636 tons of municipal waste each day, resulting in production of an additional 18 MW of electricity.

Capital and operating costs for WTE facilities are significantly higher than conventional landfill costs and typically are covered through local bonds. To ensure long-term viability, WTE facilities rely on an infrastructure that guarantees a minimum quantity of incoming solid waste. The estimated lifespan of a WTE facility is 40 years. [47]

## Developing and Evolving Energy Sources

Green remediation relies on novel applications of emerging technologies within the context of site cleanup. Technologies for producing energy from previously untapped renewable resources are quickly moving from research facilities into the field, significantly increasing the options available for site revitalization. Integrated planning for site cleanup and reuse borrows principles used in this "next generation" of renewable energy technologies but also resurrects past methods for obtaining energy from natural resources such as "old-fashioned" windmills or small-scale hydropower.

Geothermal power is energy generated by heat stored beneath the earth's surface, whether stored in shallow ground or in water and rock at depths extending several miles below ground surface. Temperatures in ground water and rock at subsurface depths up to 10 feet remain relatively constant at 50-60°F, bringing potential for geoexchange systems to be used in remediation. Aboveground treatment methods can use this energy directly through installation of air exchange pumps to heat or cool building interiors. Heat removed from indoor air also could be used to elevate the temperature of water required in a treatment process.

In contrast to heat exchange, new technologies for cold energy storage could help cool treatment processes and structures at sites located adjacent to cold water reservoirs. For example, the Halifax Regional Municipality began construction of a $3 million energy system retrofit in 2007 to meet peak air conditioning needs of buildings along the waterfront in Dartmouth, Nova Scotia, Canada. The system employs a borehole exchanger drawing cold air from 100 holes extending 600 feet below ground surface to tap energy from subsurface rock mass.

Geothermal resources at greater subsurface depths could be considered to generate electricity for long-term cleanup as well as potential sale. Geothermal power plants currently coming into operation in western states tap reservoirs of water with temperatures of 107-182°F, which are considerably lower temperatures than needed in past production. New plants operate at lower cost and greater efficiency, and emit significantly less $CO_2$ than fossil fuel plants (less than 100 pounds per megawatt hour). Potentially adverse environmental problems posed by geothermal energy production include process operations requiring deep subsurface drilling and condensed steam re-injections to draw additional heat; changes in geological stability of a region; and decreasing temperatures of water reservoirs over time. [48]

Tidal energy could provide opportunities at coastal sites undergoing long-term treatment. Although ocean tide has not yet been tapped for remediation purposes, small-scale variations relying on the flow of ground water and surface water are under evaluation. For example, DOE's Savannah River National Laboratory field tested a passive siphoning system using a synthetic tube to induce ground water flow from a contaminated aquifer into a treatment cell containing reactive material. After passing through the treatment cell, water discharges to nearby surface water. System recharge, when needed, can be accomplished easily through use of a solar powered vacuum pump to remove gas bubbles. This technology provides a passive, *in situ* alternative to P&T systems and could be used to improve performance of other low energy technologies such as permeable reactive barriers.

Adaptations of conventional treatment technologies can take advantage of energy produced by other earth processes. Passive bioventing or passive SVE rely on natural venting cycles of the subsurface to create atmospheric pressure differences capable of inducing air flow (barometric pumping) for subsurface removal of nonchlorinated hydrocarbons. Effectiveness is enhanced through simple air-control equipment such as one-way valves preventing flow of air into venting wells. The U.S. Air Force Center for Engineering and the Environment is evaluating long-term efficiency of pressure-driven systems at numerous sites, including Hanford, WA, and Hill Air Force Base, UT. Pressure-driven systems do not require mechanical pumps or electrical blowers to draw volatile contaminants from soil and provide a low-cost approach for remediation polishing following use of energy-intensive remediation technologies. Applications are limited to sites with substantial swings in barometric pressures and are most effective under aerobic conditions in shallow, unsaturated soil. Passive pressure systems commonly require more venting wells than conventional systems and often require longer time to achieve cleanup goals. [49]

The Savannah River National Laboratory is testing low power (20-40 watt) SVE systems powered by small PV modules, wind generators, or batteries. Pumps used in these applications are small and relatively unobtrusive (typically four by three inches in size) but might need replacement after one year of operation. Use of low power SVE is limited to long-term remediation polishing. [50]

## ■ *Low Energy Systems*

Passive energy remediation systems use little or no external energy to power mechanical equipment or otherwise treat contaminated environmental media. These systems commonly involve technologies such as bioremediation, phytoremediation, soil amendments, evapotranspiration covers, engineered wetlands, and biological permeable reactive barriers. Cleanup strategies can combine elements of these technologies to achieve novel hybrid systems, paving the way for yet more innovative applications.

To maximize remediation sustainability, passive energy systems should operate in conjunction with other core elements of green remediation such as water conservation and waste minimization; rely on energy efficient equipment during construction and monitoring; and consider use of renewable energy sources for auxiliary equipment. As in all cleanup actions, selection and implementation of remedies relying on passive energy technologies must account for short- and long-term environmental and cost trade-offs. Passive systems often require more time than aggressive, active energy systems to meet cleanup goals.

These systems can serve as the primary means for treating contaminated media or as secondary polishing steps once the effectiveness of more energy intensive systems

*Carbon sequestration is the removal from the emission stream of $CO_2$ or other GHG that would otherwise be emitted to the atmosphere. GHGs can be sequestered at the point of emission or removed from air, often referred to as carbon capture and storage. Emissions can be offset by enhancing carbon uptake in terrestrial ecosystems and subsequent carbon storage in soil. Vegetation serving as "carbon storage sinks" adds to the earth's net carbon storage. [51]*

begins to be outweighed by negative cost and environmental affects. Passive energy systems can increase terrestrial sequestration of $CO_2$ and other GHG, resulting in a "co-benefit" of site remediation. Monitoring and controls are required, however, to minimize potential for these systems to act as atmospheric $CO_2$ sources. For potential application in carbon offset programs becoming available in government and industrial sectors, systems must demonstrate permanence of atmospheric carbon sequestration as well as the amount of carbon being newly sequestered.

Passive energy systems inherently complement efforts to protect and restore ecological systems on contaminated lands, one of the core elements of green remediation. In addition to enhancing wildlife and vegetative habitat, ecological land use can provide features such as commercial riparian zones or recreational opportunities. Improved soil stability gained by ecological restoration also reduces erosion, slows and filters stormwater runoff, and reduces topsoil lost as dust during both remediation and reuse activities.

## Enhanced Bioremediation

Enhanced bioremediation helps microorganisms degrade contaminants in soil, ground water, or sludge. *In situ* applications involve subsurface injection of microbial enhancing substrates, which results in minimal disturbance to land or ecosystems and little fuel consumption. *Ex situ* bioremediation involves disturbance to upper soil layers and requires more field activity but avoids offsite disposal of contaminated soil and associated consumption of vehicular fuel for transport. Depending on the selected technique, *ex situ* bioremediation can produce significant amounts of nutrient-rich material available for onsite or potentially commercial offsite applications.

*In situ* aerobic bioremediation typically is enhanced by injection of oxygen and/or moisture as well as compounds influencing media temperature and pH. The end product comprises primarily $CO_2$ and water. *In situ* anaerobic bioremediation processes typically

Profile: Umatilla Army Depot, Hermiston, OR

*Cleanup Objectives: Treat 15,000 tons of soil contaminated with explosives such as trinitrotoluene (TNT) and cyclotrimethylenetrinitramine (RDX)*

*Green Remediation Strategy: Composted with locally obtained feedstock*

- *Used windrow techniques involving placement of soil in lengthy piles*
- *Periodically mixed soil with a mixture of cattle/chicken manure, sawdust, alfalfa, and potato waste*
- *Mixed soil with feedstock inside mobile buildings to control fumes and optimize biological activity*

*Results:*

- *Treated each 2,700-cubic-yard batch of soil in 10-12 days*
- *Destroyed contaminant byproducts or permanently bound the byproducts to soil or humus, achieving non-detectable concentrations of explosives*
- *Provided $150,000 potential revenue from sale of humus-rich soil*
- *Saved an estimated $2.6 million compared to incineration, a common alternative for explosives treatment*
- *Avoided significant fossil fuel consumption by an incinerator*
- *Avoided fuel costs and consumption associated with transporting soil to an offsite incinerator or transferring ash generated by an onsite mobile incinerator*

*Property End Use: Conversion under base realignment and closure*

(U.S. EPA/OSWER, 1997)

are enhanced by injection of an electron donor substrate such as vegetable oil to promote suitable conditions for microbial growth. If the appropriate contaminant-degrading microbes are not present in sufficient quantity, additional microbes will be injected (bioaugmentation). Some applications targeting ground water create flow-through bioreactors or permeable reactive barriers constructed of organic material.

*Ex situ* bioremediation of soil may be conducted through a slurry process, whereby contaminated soil is excavated and mixed with water to suspend solids and provide contact with microorganisms. In contrast, solid-phase bioremediation involves placement of contaminated soil in a treatment cell or aboveground structure where it is tilled with water and nutrients. Land farming, biopiles, and composting are among the solid-phase bioremediation techniques producing enriched soil for potential use in landscaping and agriculture at revitalized sites. [52]

*Ex situ* enhanced bioremediation can play a significant role in green remediation by helping to rebuild organic content of soil, increase soil aeration, improve water infiltration, increase moisture retention, and stimulate vegetation growth. BMPs of green remediation include methods to control soil erosion and sediment transport through strategies such as topsoil stockpiling, installation of straw barriers, and placement of permeable ground cover to prevent soil compaction caused by heavy machinery. The practices also encourage air protection strategies such as use of clean fuel in on-road vehicles, retrofitting of diesel equipment, and minimal idling of heavy machinery.

## Phytoremediation

Phytoremediation uses plants to remove, transfer, stabilize, or destroy contaminants in soil, sediment, and ground water. This technology encompasses all biological, chemical, and physical processes influenced by plants, including the root biomass (rhizosphere). Treatment mechanisms include:

- Phytoextraction (phytoaccumulation and phytotranspiration) involving contaminant uptake by plant roots and subsequent storage or transpiration of contaminants in plant shoots and leaves,
- Enhanced rhizosphere biodegradation, whereby contaminants break down in soil or ground water surrounding plant roots,
- Phytodegradation, whereby plant tissue metabolizes contaminants, and

Profile: Carswell Golf Course, Fort Worth, TX

*Cleanup Objectives: Biodegrade subsurface VOCs through reductive dechlorination and control contaminant migration*

*Green Remediation Strategy: Planted 660 cottonwood trees across 4,000 square meters in 1996 to:*
- *Establish root biomass promoting activity of indigenous microbes*
- *Enhance transpiration of ground water through the trees, helping to control hydraulic gradient and downgradient migration of VOCs*

*Results:*
- *Produces virtually no process residuals*
- *Reduced VOC concentrations in ground water approximately 65% within four years after the plantings,*
- *Demonstrates increased treatment efficacy over time according to plant growth*
- *Incurred costs of only $2,100 for plants and $10,000 for irrigation*
- *Supported transfer of property to community as part of base closure, without disruption to ongoing activities*

*Property End Use: Recreation*

*[U.S. EPA/OSRTI, 2005]*

- Phytostabilization, whereby plants produce chemical compounds to immobilize contaminants at the root/soil interface.

Plant communities used in phytostabilization can serve as significant carbon storage sinks. Carbon uptake during photosynthesis increases plant growth rate, in turn increasing biomass capability to capture and store atmospheric carbon. BMPs for phytoremediation rely on the use of native, noninvasive, and non-noxious plants. While selection of suitable plants is site-specific, vegetation with capability to treat contaminated soil or ground water includes common plants such as hybrid poplars, Bermuda grass, and alpine pennycress. Phytoremediation systems can be constructed and maintained at low cost, depending upon site characteristics and goals, and require minimal equipment once installed.

LEED-based water efficiency goals for phytoremediation could include 50% use of non-potable water for irrigation, where needed. Methods to minimize water consumption include use of drip irrigation techniques, greywater reclaimed from industrial or small-scale potable water systems, and high efficiency equipment or climate-based controllers.

Phytoremediation can be used to treat organic compounds through the process of mineralization, and heavy metals or other inorganic compounds through the processes of accumulation and stabilization. The technology can be applied *in situ* to soil, sediment, or ground water. Applications involving no accumulation of contaminants (and associated disposal of plants) particularly complement land use that is dependent on bioversity, such as greenspace. [53]

## Soil Amendments

Soil amendments are organic materials that can be applied *in situ* to enhance contaminant biodegradation by subsurface microorganisms and to decrease availability of metal contaminants. Soil amendments help restore degraded lands and ecosystems by:

- Improving water retention (resulting in enhanced plant growth and drought resistance) and other soil properties such as pH balance,
- Supplying nutrients essential for plant growth, including nitrogen and phosphorous as well as essential micronutrients such as nickel, zinc, and copper, and
- Serving as an alternative to chemical fertilizers that incur additional project costs and potentially introduce human health or environmental concerns.

In contrast to the quick release of nutritional elements following application of inorganic fertilizers, organic nutrients in soil amendments are released slowly, resulting in more efficient plant uptake and subsequent growth. Nutrients bound in organic matter also are less water soluble, rendering them less likely to leach into ground water or migrate as runoff into surface water. The process of applying soil amendments can be completed at a relatively low cost and often produces soil for use in site redevelopment. Applications must include precautions, however, to avoid potential nutrient- or metals-loading that contributes to nonpoint pollution of other environmental media.

“Biosolid recycling” of stabilized sewage sludge, which is increasingly used by municipalities as an alternative to incineration, provides a significant source of organic material needed to amend soil at hazardous waste sites. This approach converts organic wastewater treatment material into products for beneficial use such as bulk application in agriculture or pellets in commercial fertilizers. Generation and use of biosolids are subject to federal, state, and local requirements to ensure that treatment systems sufficiently sterilize organic material; excess field application is avoided; sufficient post-application time is allowed before plant harvesting; and metal content is within safe levels. [54]

Profile: Upper Arkansas River, Leadville, CO

*Cleanup Objectives:* *Restore soil and ecosystems severely degraded by past mining activities conducted upstream*

*Green Remediation Strategy:* *Introduced biosolids and assorted soil amendments*
- *Applied 100 dry tons (pellets) of biosolids to each of 20 target acres along an 11-mile stretch of the river*
- *Mixed biosolids with lime to reduce soil acidity, consequently increasing plant viability and metal insolubility*
- *Seeded native plants and quick-growing ryegrass*
- *Added compost and woody material as additional plant nutrients*
- *Added wood chips to reduce nitrogen (nutrient) leaching*
- *Covered amended soil with native hay to promote plant growth and seeding*

*Results:*
- *Revegetated denuded acreages*
- *Reduced concentrations and bioavailability of zinc and other metals through bioremediation, phytoremediation, and solubility reduction*
- *Neutralized soil to levels supporting healthier ecosystems*
- *Reduced soil erosion, river channel degradation, and property loss*
- *Reestablished communities of native plants such as white yarrow and tufted hairgrass*

*Property End Use:* *Agriculture and recreation*

## Evapotranspiration Covers

Evapotranspiration (ET) covers are waste containment systems providing an alternative to conventional compacted-clay covers (caps) that might insufficiently prevent percolation of water downward through the cover to the waste.  ET covers use one or more vegetated soil layers to retain water until it is transpired through vegetation or evaporated from the surface of soil.  An ET cover also is known as a water balance cover, alternative earthen final cover, vegetative landfill cover, soil-plant cover, or store-and-release cover.  These systems increase vegetative growth, help establish small wildlife habitat, and provide significant opportunities for $CO_2$ capture and sequestration.

Effective cover designs incorporate methods to control percolation and moisture buildup and to promote surface water runoff.  ET covers rely on a soil layer's capacity for water storage, instead of engineered material with low hydraulic conductivity, to minimize percolation.  Cover designs emphasize use of:

- Native vegetation to increase evapotranspiration, and
- Local soil to streamline construction, minimize project costs, and avoid fuel consumption associated with imported soil.

ET cover systems generally are constructed as monolithic barriers or capillary barriers.  A monolithic cover (or monofill cover) uses a single vegetated layer of soil to retain water until it is either transpired through vegetation or evaporated from the soil surface.  A capillary barrier cover system uses a similar clay layer typically underlain by sand or gravel to cause infiltrating water to wick at the layer interface.

Profile: Fort Carson, Colorado Springs, CO

*Cleanup Objectives: Contain a 15-acre hazardous waste landfill*

*Green Remediation Strategy: Installed a four-foot-thick monolithic ET cover*
- *Applied biosolids from an onsite wastewater treatment plant*
- *Installed a layer of straw mulch to prevent erosion*
- *Revegetated with native prairie grass resistant to drought and disease*
- *Provided uncompacted soil more conducive to plant growth than conventional earthen covers*

*Results:*
- *Reduced potential for desiccation*
- *Reclaimed sludge otherwise destined for landfill disposal*
- *Enhances visual aesthetics contrasting to adjacent asphalt cover*
- *Saved nearly $1.5 million in construction costs compared to a conventional cover*
- *Incurs annual O&M costs averaging $75,000, relatively higher than conventional covers*

*Property End Use: Open space*

(McGuire, *et. al.*, 2001)

Costs for construction could be 50% lower for ET covers than for conventional covers. O&M costs for an ET cover, however, depend heavily on site-specific factors such as the need for light irrigation of vegetation, nutrient additions, erosion and biointrusion controls, and related field work. Applications often involve higher energy consumption associated with increased O&M activity. These systems are anticipated to cover many small landfills in arid or semi-arid climates over the coming decade, particularly on military properties. [55]

## Engineered Wetlands

Wetlands serve as biofilters capable of removing solid or dissolved-phase contaminants from ground water via passage of water through the system, while using no external sources of energy. Engineered wetlands are semi-passive networks of constructed cells specifically designed to treat contaminants in surface and/or ground water. Engineered systems accelerate cleanup through use of auxiliary components for increased control and monitoring of the treatment cells, and consequently carry higher extrinsic energy demands.

Wetlands contain rich microbial communities housed in sediment typical of marsh or swamps. In addition to biodegrading contaminants, engineered wetlands can eliminate discharge to a water treatment plant, create habitats important to healthy ecosystems, and enhance visual aesthetics of a degraded site through addition of greenspace.

Traditionally, natural or engineered wetland applications were limited to treatment of stormwater and municipal wastewater. Increased demand for wetland-based treatment systems has resulted in technology advancements enabling applications for acid mine drainage, treatment process wastewater, and agricultural waste streams. Evaluation and preliminary design of engineered wetlands as a cleanup remedy requires early assessment of site-specific characteristics and remediation/reuse goals:

- Confirming anticipated site reuse and determining whether use is compatible with a sustainable wetland,
- Estimating the time needed to establish a wetland system,

Profile: British Petroleum Site, Casper, WY

*Cleanup Objectives:* *Remediate gasoline-contaminated ground water for 50 to 100 years*

*Green Remediation Strategy:* *Installed an engineered, radial-flow constructed wetland system*

- *Designed wetland treatment cells for subsurface location to increase operational control, reduce offensive odors and insects, and avoid disruption of surface activity*
- *Constructed treatment beds of crushed concrete reclaimed from demolition of the site's former refinery*
- *Insulated each treatment cell with a six-inch layer of mulch to withstand temperatures reaching -35° F*
- *Installed native, emergent wetland plants such as bulrushes, switchgrass, and cordgrass in each treatment cell*
- *Employed "Smart Growth" principles to complement site conversion for mixed use*

*Results:*

- *Treats up to 700,000 gallons of contaminated ground water each day*
- *Achieves non-detectable concentrations of benzene and other hydrocarbons*
- *Operates year-round despite cold climate*
- *Incurred construction costs totaling $3.4 million, in contrast to $15.9 million for the alternative P&T system employing air stripping and catalytic oxidation*

*Property End Use:* *Office park and recreation facilities including golf and kayak courses*

(Wallace, 2004)

- Identifying optimal biological and chemical treatment mechanisms,
- Avoiding use of non-native, invasive, or noxious plants,
- Removing certain ground water contaminants such as mercury prior to wetland treatment, and closely monitoring the concentrations during treatment, and
- Accounting for seasonal variance in system performance and maintenance.

Designs need to account for future O&M needs, particularly for small-scale systems. If a wetland is used for buffering, rejuvenation is typically needed over time. Rejuvenation involves addition of buffering material such as limestone and removal of some sediment to maintain system grade. [56, 57]

## Biowalls

A permeable reactive barrier (PRB) is an *in situ* ground water treatment technology that combines a passive chemical or biological treatment zone with subsurface fluid-flow management. PRB construction commonly involves subsurface placement of selected reactive media into one or more trenches perpendicular to and intersecting ground water flow. Passage of ground water through the barrier is driven by the natural hydraulic gradient, requiring no external energy.

PRBs employing organic material as reactive media, otherwise known as "biowalls," are used to treat ground water containing chlorinated solvents and other organic contaminants. Reactive media typically comprise readily available, low-cost materials such as mulch, woodchips, or agricultural byproducts mixed with sand. Enhanced microbial activity within the organic material stimulates contaminant biodegradation as water slowly passes through the barrier. Sequential breakdown of contaminants results in both aerobic and anaerobic zones of the treatment area.

Profile: Altus Air Force Base, OK

*Cleanup Objectives:* *Biodegrade a VOC hotspot 10-18 feet below ground surface in a remote location*

*Green Remediation Strategy:* *Installed a 10,000-square-foot subsurface biowall of organic material*

- *Filled trenches with woody waste supplied by a local municipality and cotton gin trash obtained from the local cotton industry*
- *Relied exclusively on power from a 200-watt PV array to recirculate ground water*
- *Employed a small submersible pump designed for solar applications and suitably sized for low rates of ground water transfer*

*Results:*

- *Demonstrates continued biodegradation of VOCs*
- *Transfers 1,300 cubic meters of carbon-enriched leachate into the aquifer each year*
- *Maintains a ground water flow rate of 928 gallons each day*
- *Avoided significant cost for connection to the electricity grid*
- *Incurred capital costs of only $2,300 for the pump/solar system*
- *Provided a low-maintenance alternative for potentially extended cleanup duration*
- *Provides opportunity of re-using solar equipment (with 20- to 30-year lifespan) at other locations or sites*

*Property End Use:* *Continued military operations*

(U.S. EPA/OSWER, 2007(c))

Biowall installation involves varying degrees of soil excavation and field mobilization, depending on site and contaminant characteristics. Typical biowall dimensions are 1.5-3 feet in width and 25-35 feet in depth, with variable length to accommodate width of the contaminant plume. Configurations could involve a single continuous trench or a series of trenches angled for maximum plume capture. Once installed, biowalls require little field work beyond routine monitoring. Periodic replenishment of the reactive medium can be accomplished by injecting soluble organic substrate such as common soybean oil. Due to the low cost of organic materials, biowalls can be installed for one-fourth to one-third the cost of PRBs using zero valent iron, a commonly used reactive medium. [58]

Operating on the same principles as a biowall, a "bioreactor" additionally integrates a recirculation system to transfer downgradient water to the trench filled with organic media. Nutrient-rich leachate exiting the bioreactor is transferred continuously to the aquifer. Ground water pumping from the collection trench can be powered by renewable energy sources due to the low rate of water exchange required.

## Monitored Natural Attenuation

Monitored natural attenuation (MNA) relies on nature's biological, chemical, or physical processes to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in environmental media under favorable conditions. MNA uses an *in situ* approach involving close control and monitoring to achieve remediation objectives within a reasonable time frame. MNA processes include biodegradation, dispersion, dilution, sorption, volatilization, radioactive decay, and chemical or biological stabilization, transformation, or destruction of contaminants; degradation or destruction is preferred.

MNA is suited for sites with low potential for contaminant migration and where application ensures that all remedy selection criteria are met. MNA can be combined with aggressive remediation measures such as ground water extraction and treatment or used as a polishing step following such measures. Advantages of MNA generally include:

- Less remediation-generated waste, reduced potential for cross-media transfer of contaminants, and reduced risk of onsite worker exposure *to* contaminants,
- Less environmental intrusion and smaller treatment-process footprints on the environment, and
- Potentially lower remediation costs compared to aggressive treatment technologies.

When compared to aggressive treatment systems, potential disadvantages of MNA include:

- More complex and costly site characterization, longer periods needed to achieve remediation objectives, and more extensive performance monitoring (with associated energy consumption),
- Continued contamination migration or renewed contaminant mobility caused by hydrologic or geochemical changes, and
- Institutional controls to ensure long-term protectiveness and more public outreach to gain acceptance. [59]

# Section 5: Tools and Incentives

Growing numbers of tools and incentives are available to site remediation and redevelopment managers for planning, financing, and implementing green projects. Several programs within EPA's ***Clean Energy*** initiative provide technical assistance and policy information, foster creation of public/private networks, and formally recognize leading organizations that adopt clean energy policies and practices. [http://www.epa.gov/cleanenergy]

- The ***Green Power Partnership*** helps organizations to buy green power designed to expand the market of environmentally preferable renewable energy sources. [http://www.epa.gov/greenpower]

- ***State Utility Commission Assistance*** is offered to utility regulators exploring increased use of renewable resources for energy production, energy efficiency, and clean-distributed generation such as co-generated heat and power. [http://www.epa.gov/cleanenergy/energy-programs/suca.html]

- The ***National Action Plan for Energy Efficiency*** engages public/private energy leaders (electric and gas utilities, state utility regulators and energy agencies, and large consumers) to document a set of business cases, BMPs, and recommendations designed to spur investment in energy efficiency. [http://www.epa.gov/cleanenergy/energy-programs/napee/index.html]

- The ***Clean Energy-Environment State Partnership Program*** and ***Clean Energy-Environment Municipal Network*** support development and deployment of emerging technologies that achieve cost savings through energy efficiency in residential and commercial buildings, municipal facilities, and transportation facilities. [http://www.epa.gov/cleanenergy/energy-programs/state-and-local/index.html]

EPA's ***Environmentally Responsible Redevelopment and Reuse*** ("ER3") Initiative uses enforcement incentives to encourage developers, property owners, and other parties to implement sustainable practices during redevelopment and reuse of contaminated sites. [http://www.epa.gov/compliance/cleanup/redevelop/er3/]

As lead agency for federal energy policy, DOE continues to expand and establish new programs aimed at reducing the use of non-renewable energy sources and increasing energy efficiency.

- EERE offers grants or cooperative agreements to industry and outside agencies for renewable energy and energy efficiency research and development. Assistance is available in the form of funding, property, or services. In fiscal year 2004, EERE awarded $506 million in financial assistance. [http://www1.eere.energy.gov/financing/types_assistance.html]

- EERE also provides grants to state energy offices for energy efficiency and renewable energy demonstration projects as well as analyses, evaluation, and information dissemination. [http://www.eere.energy.gov/state_energy_program/]

State and local mechanisms are evolving quickly to meet national energy goals for the coming decades. State renewable energy portfolios help meet these goals by offering (1) third-party funding mechanisms that support public/private partnerships for generation of electricity from renewable resources, (2) reduced purchasing rates for electricity generated from renewable resources, and (3) tax credits for energy production from renewable resources. The ***Database of State Incentives for Renewables and Efficiency*** (DSIRE) provides quick access to information about renewable energy incentives and regulatory policies administered by federal and state agencies, utilities, and local organizations. Information is updated frequently through a partnership among the North Carolina Solar Center, the Interstate Renewable Energy Council, and DOE. [www.dsireusa.org/]

State authorities are working with commissioned utilities to develop a host of tools and incentives for using green practices. Programs in Minnesota and California demonstrate some of the mechanisms becoming available.

- The Minnesota Pollution Control Agency (MPCA) ***Green Practices for Business, Site Development, and Site Cleanups: A Toolkit*** provides online tools to help organizations and individuals make informed decisions regarding sustainable BMPs for use, development, and cleanup of sites. [http://www.pca.state.mn.us/programs/p2-s/toolkit/index.html]

- The ***State of California Self-Generation Incentive Program*** *(SGIP)* provides incentives for installation of renewable energy systems and rebates for systems sized up to 5 MW. Qualifying technologies include PV systems, microturbines, fuel cells, and wind turbines. [http://www.pge.com/selfgen/]

# Section 6: Future Opportunities

Significant opportunities exist to increase sustainability of site remediation while helping to meet national, regional, and state or local goals regarding natural resource conservation and climate change. Decision-makers are encouraged to take advantage of newly demonstrated or emerging technologies and techniques in ways that creatively meet the objectives of site cleanup as well as revitalization. Effective green remediation can provide a range of new opportunities.

► *Building Stronger Communities*

- Renew or form new partnerships among organizations and individuals with common environmental, economic, and social concerns, including energy independence,
- Identify optimal methods that stakeholders can use to influence the direction of remediation and revitalization and to maintain an active voice throughout a project, and
- Work more efficiently with local engineering firms involved in cleanup design, construction, and operations.

► *Expanding the Options for Site Reuse*

- Evaluate options presented by a larger universe of potential developers,
- Identify new solutions for unresolved site issues, and
- Facilitate new incentives for current site owners.

► *Increasing Economic Gains*

- Integrate new energy-related businesses into local and regional infrastructures,
- Demonstrate specific technical needs to be met by commercial product and service vendors, and
- Foster government initiatives that reward businesses employing sustainable practices.

► *Increasing Environmental Benefits of Cleanups*

- Enhance environmental conditions beyond immediate target areas,
- Participate in state and local initiatives collectively working to meet goals for natural resource and energy conservation, and
- Showcase more sustainable cleanup and revitalization strategies that readily apply to other sites.

Additional information on opportunities and tools for implementing green remediation is frequently uploaded to the EPA Office of Superfund Remediation and Technology Innovation's CLU-IN Web page on ***Green Remediation*** (http://www.cluin.org/greenremediation). Future electronic updates to this primer also will be available on CLU-IN to share emerging information on green remediation.

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# Section 8: General Resources

Expanding numbers of technical, planning, and financial resources for implementing green remediation are available from federal or state agencies, academic organizations, and sector-specific trade associations. The following documents and online resources provided key information for this primer and are readily available to readers interested in learning more about specific topics.

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2. U.S. EPA online. *Climate Change*. http://www.epa.gov/climatechange/
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