United States Environmental Protection Agency
Office of Land and Emergency Management (5203)
EPA 542-F-16-001 December 2015 Update

Green Remediation Best Management Practices: An Overview

A fact sheet about the concepts and tools for using best management practices to reduce the environmental footprint of activities associated with assessing and remediating contaminated sites

www.clu-in.org/greenremediation

The Principles and Core Elements

As part of its mission to protect human health and the environment, the U.S. Environmental Protection Agency (EPA) develops and promotes innovative strategies that restore contaminated sites to productive use, reduce associated costs and promote environmental stewardship. The Agency recognizes that the process of cleaning up a hazardous waste site uses energy, water and other natural or processed material resources and consequently creates an environmental footprint of its own. EPA's *Principles for Greener Cleanups* (the Principles) outline the Agency's policy for considering the footprint.[1]

Green remediation is the process of examining the environmental footprint of site cleanup activities and taking steps to minimize the footprint. Green remediation best management practices (BMPs) can help project managers and other stakeholders apply the Principles while maintaining the cleanup objectives and ensuring protectiveness of a site-specific remedy. The ASTM Standard *Guide for Greener Cleanups* (E2893-13)[2] offers a collection of greener cleanup BMPs.

Green remediation BMPs focus on the core elements of greener cleanups:

- Minimize total energy use and increase the percentage from renewable energy.
- Minimize emission of air pollutants and greenhouse.
- Minimize water use and preserve water quality.
- Conserve material resources and minimize waste.
- Protect land and ecosystem services.

Where and When to Use the BMPs

Green remediation BMPs may be applied to cleanup actions taken at almost any hazardous waste site, whether conducted under federal, state or local cleanup programs. Success in reducing the environmental footprint of cleanup activities has been demonstrated at sites involving:

- Superfund remedial or removal actions.
- Corrective actions under the Resource Conservation and Recovery Act.
- Federally owned or operated facilities.
- Cleanup of leaking underground storage tanks.
- Brownfield site cleanups.
- Voluntary or mandatory actions under state programs.

Green remediation strategies emphasize a whole-site approach to be used throughout the life of a cleanup project, including:

- Site investigation.
- Remedy design.
- Remedy construction.
- Remedy operation and maintenance.
- Long-term monitoring.

Early incorporation of a green remediation strategy into project documents such as a feasibility study and cleanup service contract can help attain cost efficiencies throughout the project life and integrate site reuse plans into the cleanup infrastructure.

A process for screening, prioritizing, selecting and implementing BMPs in a verifiable manner is provided in the ASTM *Standard Guide for Greener Cleanups* (E2893-13).[2]

BMPs in the Field

- Reduce **energy** loads of motorized equipment such as pumps by using variable rather than single-speed frequency drives.

Massachusetts Military Reservation

- Power cleanup equipment with onsite sources of clean, renewable energy to minimize **air** emissions.

Pennsylvania Mine

Tools for BMP Implementation

BMPs presented in this fact sheet series address common remediation technologies, frequently encountered cleanup scenarios, or aspects shared in most cleanup projects. Specific topics include:

- Site investigation.
- Excavation and surface restoration.
- Soil vapor extraction and air sparging technologies.
- Pump and treat technologies.
- Bioremediation.
- In situ thermal technologies.
- Landfill cover systems and associated energy production.
- Leaking underground storage tank systems.
- Mining sites.
- Renewable energy applications.
- Clean fuel and emission technologies.
- Materials and waste management.
- EPA's methodology for environmental footprint assessment.

For large or complex cleanups, stakeholders may wish to quantify an existing or potential environmental footprint of the cleanup activities. Use of EPA's *Methodology for Evaluating and Reducing a Project's Environmental Footprint* can aid this process by identifying the largest footprint contributions.[3] Findings can then be used to target BMPs with the greatest potential to reduce the footprint. The methodology involves 21 metrics and a seven-step quantification process supported by planning checklists and references such as common conversion factors and typical energy demands of field equipment. EPA's supporting set of *Spreadsheets for Environmental Footprint Analysis* (SEFA) is available to help interested parties compile the data needed for this methodology.[4]

Sample Metrics & Units

- Renewable energy generated onsite (kilowatts)
- Greenhouse gas emitted onsite (tons)
- Waste recycled (tons)
- Treated water used onsite (pounds)
- Barren ground surface (acres)

EPA continues to identify additional BMPs for greener cleanups and to periodically update these "BMP fact sheets" as a means to foster BMP use in normal business operations for site cleanup. This series is part of a compendium of tools available on the CLU-IN *Green Remediation Focus* website maintained by EPA's Office of Superfund Remediation and Technology Innovation.[5] The website also contains:

- Monthly announcements about new tools and upcoming events.
- Profiles of projects employing green remediation BMPs.
- In-depth reports on using EPA's methodology for footprint assessment.
- Links to related technical reports and online software or calculators.
- Information about greener cleanup initiatives and policies undertaken by state agencies.

♦ Avoid stormwater runoff and resulting soil erosion near treated **water** drainage outlets by installing deep-rooted plants, emplacing pervious mats for anchorage, and stabilizing rocks along banks.
Lawrence Aviation Industries Superfund Site

♦ Segregate clean excavated soil from **material** requiring treatment or offsite disposal as **waste** and stockpile it as a source of borrow material for remedy construction and future site needs.
Elizabeth Mine Superfund Site

♦ Surgically remove rather than clear-cut trees or small plants obstructing remedy construction or maintenance, to protect **land** and **ecosystems**.
Barksdale Air Force Base

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

References

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[4] U.S. EPA. *Spreadsheets for Environmental Footprint Analysis* (SEFA). www.clu-in.org/greenremediation/methodology/#SEFA
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United States Environmental Protection Agency | Office of Solid Waste and Emergency Response (5102G) | EPA 542-F-08-012 December 2008

Green Remediation: Best Management Practices for Excavation and Surface Restoration

Office of Superfund Remediation and Technology Innovation | Quick Reference Fact Sheet

This fact sheet is one of a series describing best management practices (BMPs) for green remediation, which holistically addresses a cleanup project's (1) energy requirements, (2) air emissions, (3) impacts on water, (4) material consumption and waste generation, (5) impacts on land and ecosystems, and (6) long-term stewardship actions. BMPs can be used for sustainable removal or cleanup activities at contaminated sites under Superfund, corrective action, underground storage tank, and brownfield cleanup programs.

Some green remediation strategies stem from environmentally progressive practices of business market sectors such as construction. Others build new elements such as green purchasing into traditional practices of the remediation sector. Yet more evolving BMPs incorporate innovative technologies that can be readily adapted to increase cleanup sustainability.

Overview

Excavation in varying degrees is often undertaken at contaminated sites to:

- Address immediate risk to human health and/or the environment as part of immediate or long-term removal actions
- Prepare for implementation of in situ or ex situ remediation technologies, which often involves building or other structural demolition
- Address soil or sediment hot spots for which other remedies may be infeasible due to extremely high cost, long duration, or technical constraints

Many opportunities exist to reduce the negative impacts of excavation, which commonly include soil erosion, high rates of fuel consumption, transport of airborne contaminants, uncontrolled stormwater runoff, offsite disposal of excavated material, and ecosystem disturbance. Decisions regarding excavation processes and targets affect follow-up land and surface water restoration strategies as well as ultimate land use.

Planning for Excavation and Restoration

Early and integrated project planning allows the (typically early) excavation period to set the stage for sharing of resources, infrastructures, and processes throughout site cleanup and reuse. Early BMPs include:

- Incorporation of green requirements into product and service procurements
- Installation of a modular renewable energy system to meet low energy demands of field equipment, other remedies, and construction or operational activities associated with site reuse
- Dynamic work planning; for example, treated excavation material found unnecessary as backfill can be put to beneficial use at onsite or offsite locations
- Consideration of environmental and economic tradeoffs involved in onsite versus offsite treatment of excavated soil or sediment
- Balance of trade-offs associated with onsite versus offsite disposal of contaminated soil or other material
- Early and continuous scouting for onsite or nearby sources of backfill material for excavated areas
- Establishment of decision points that could trigger in situ treatment instead of excavation in subareas
- Integrated schedules allowing for resource sharing and fewer days of field mobilization

Profile: Re-Solve, Inc. Superfund Site, North Dartmouth, MA

- Excavated 36,000 yd^3 of polychlorinated biphenyl (PCB)-contaminated soil above the water table, treated soil through onsite low-temperature desorption, backfilled with treated soil, and covered with 18 inches of gravel cap
- Excavated 3,000 yd^3 of PCB-contaminated sediment from one acre of wetlands, treated excavated sediment through onsite low-temperature desorption, and restored the wetlands to natural conditions
- Reduced carbon dioxide emissions by104 tons each year due to lower propane consumption after ground-water treatment optimization
- Avoided significant fossil fuel consumption for offsite transport and disposal of untreated soil or sediment through onsite treatment
- Converted the gravel-capped area to a four-acre native upland meadow cover that enhances local habitat and re-established native species

Energy Requirements

Determining the optimum extent of excavation relies on accurate delineation of the contaminant plume(s). Use of the Triad approach for site investigations can reduce field mobilizations and associated fuel consumption through systematic planning, dynamic work activities, and real-time measurements.

BMPs that can help reduce fuel consumption as well as waste generation during site investigations include:

- Using direct-push technology instead of rotary drilling rigs to reduce drilling duration (by as much as 50-60%), avoid drilling fluids, and eliminate drill cuttings; this technique may be infeasible in applications limiting the depth, type, weight, or volume of target samples or the installation of new ground water wells
- Re-using wells and subsurface bore holes throughout investigations, remediation, and long-term monitoring
- Using field test kits whenever possible and selecting the nearest qualified laboratory for confirmatory analyses or contaminants outside the scope of test kits

Procurement of goods and services offers other opportunities for reducing fuel consumption:

- Purchase materials from one supplier of locally produced products to reduce need for delivery fuels
- Select local providers for field operations
- Coordinate outside services and service providers to minimize transport of equipment and reduce costs

Fuel consumed during transfer of excavated soil or other materials to landfills can be reduced by:

- Selecting the closest waste receiver
- Investigating alternate shipping methods such as rail lines
- Identifying opportunities for resource sharing with other waste haulers

Diesel fuel consumption by construction machinery and equipment can be conserved by:

- Selecting suitably sized and typed equipment
- Instructing workers to avoid engine idle and using machinery with automatic idle-shutdown devices
- Employing auxiliary power units to power cab heating and air conditioning when a machine is unengaged
- Performing routine, on-time maintenance such as oil changes to improve fuel efficiency
- Repowering an engine or replacing it with a newer, more efficient one

Auxiliary equipment such as electricity generators or wood chippers can be powered by small photovoltaic (PV) systems. Installations can involve placement of PV panel support poles on small concrete pads for short-term use. Micro-scale solar power can be used for small devices such as flashlights, lamps, and temperature-controlled containers.

New technology for installation of ground-mounted PV systems requires no concrete, reduces subsurface disturbance, and increases options for equipment reuse.

Air Emissions

Field generation of contaminated or uncontaminated dust and mobilization of volatile organic compounds can be reduced by new and traditional BMPs such as:

- Covering excavated areas with biodegradable fabric that also can control erosion and serve as a substrate for favorable ecosystems, or with synthetic material that can be reused for other onsite or offsite purposes
- Spraying water in vulnerable areas, in conjunction with water conservation and runoff management techniques
- Securing and covering material in open trucks hauling excavated material, and reusing the covers
- Revegetating excavated areas as quickly as possible
- Limiting onsite vehicle speeds to 10 miles per hour

Greenhouse gas (GHG) and particulate matter (PM) emissions from mobile sources can be reduced through use of:

- Equipment retrofits involving low-maintenance multistage filters for cleaner engine exhaust
- Cleaner fuel such as ultra-low sulfur diesel, wherever available (and as required by engines with PM traps)
- Biodiesel, particularly if made from recycled byproducts

Impacts on Water

Green remediation strategies help reduce consumption of fresh water, reclaim or reuse uncontaminated water, minimize potential for waterborne contamination, and minimize introduction of toxic processing materials.

- Cover soils with biodegradable tarps and mats, rather than spraying with water, to suppress dust while potentially enhancing soil fertility

- Explore options for reusing operational graywater, capturing rainwater, and returning unused water to surface bodies instead of discharging it to a public sewer system
- Use phosphate-free detergents instead of organic solvents or acids to decontaminate sampling equipment, if not required for certain contaminants
- Employ rumble grates with a closed-loop graywater washing system (or an advanced, self-contained wheel washing system) to minimize vehicle tracking of sediment and soil across non-work areas or offsite

BMPs for excavation of contaminated sediments in surface water or wetlands focus on slurry management and disposal:

- Evaluate fuel efficiency and sizing suitability of dredging equipment if multiple options can achieve site-specific cleanup goals
- Overlay synthetic barriers and fluid collection systems on ground surfaces of staging areas and where excavated material is dewatered
- Use dewatering processes that maximize water recycling, and consider automated systems to account for sediment variability
- Investigate the potential for treated slurry water to be beneficially reused in other cleanup activities prior to discharge
- Investigate opportunities to transfer treated slurry water for use in non-remedial applications such as irrigation or wetlands enhancement
- Consider the use of geotextile bags or nets to contain excavated sediment, facilitate sediment drying, and increase ease of sediment placement or transport
- Check for toxic contents in synthetic coagulants used in the field and avoid spillage
- Evaluate potential for excavated areas to serve as retention basins in final stormwater control plans

BMPs for restoration of surface water and adjacent banks after sediment excavation rely on low impact development techniques that reduce impacts of built areas and promote natural movement of water:

- Undercut surface water banks in ways that mimic natural conditions
- Retrieve dead trees during excavation and later reposition them as habitat snags
- Select and place suitably sized and typed stones into water beds and banks

Profile: Paducah Gaseous Diffusion Plant, Paducah, KY

- Used Triad to integrate site characterization, remedial activities, and cleanup verification in a 7,000 foot^2 area with potential uranium and PCB contamination
- Convened federal and state agencies to develop a conceptual site model and dynamic work plan prior to beginning any field work
- Used investigative tools requiring no soil disturbance (laser-based gamma "walkover" surveys (GWS) and x-ray fluorescence (XRF) with gamma spectroscopy) and techniques requiring few analytical samples and minimal sampling waste (PCB test kits, multi-increment sampling, and adaptive compositing)
- Integrated field information involving 24,000 GWS data points, hundreds of XRF measurements, and nearly 400 surface soil increments, which resulted in a need for laboratory confirmation on only 23 samples instead of an estimated 300 using a traditional field approach
- Surgically excavated 13 meter^3 of uranium-contaminated soil and confirmed PCB concentrations in non-excavated areas were below risk-based cleanup targets
- Completed investigatory, removal, and verification activities in a single 10-day field mobilization, resulting in less dust generation, fuel consumption, and site disturbance
- Saved significant time and costs in reaching cleanup closure when compared to traditional, static work plans involving reiterative activities

Material Consumption and Waste

Countless and diverse man-made products are purchased and used during excavation, such as personal protective equipment (PPE), synthetic sheeting, and routine business materials. Green purchasing considers product life cycles and gives preference to:

- Products with recycled and bio-based instead of petroleum-based contents
- Products, packing material, and disposable equipment with reuse or recycling potential
- Product contents and manufacturing processes involving nontoxic chemical alternatives

To reduce the volume of single-use material such as PPE and sampling materials, activity planning can reflect reduced traffic between hot and clean zones and fewer days in which work is performed. BMPs for waste management include:

- Establishing staging areas prior to any digging
- Salvaging uncontaminated and pest- or disease-free organic debris for use as infill, mulch, or compost
- Reclaiming and stockpiling uncontaminated soil for use as fill or other purposes such as habitat creation
- Salvaging uncontaminated objects with potential recyle, resale, donation, or onsite infrastructure value such as steel, concrete, granite, and storage containers; waste coordinators are available in many states to assist in decisions regarding beneficial reuse or exposure risk

Impacts on Land and Ecosystems

A primary BMP for minimizing the negative impacts on land and ecosystems is to perform an inventory (including detailed photographs and videos) of ecological species, land contours, and drainage patterns prior to digging. Baseline inventories will facilitate restoration that best recreates original conditions. Other BMPs include:

- Establishment of minimally intrusive and well-designed traffic patterns for onsite activities and plans to reduce off-site traffic congestion
- Placement of metal grates over a thick mulch layer in onsite traffic corridors to avoid soil compaction and associated reduction in subsurface water infiltration
- Construction of long-term structural controls such as earth dikes and swales to prevent upgradient surface flow into excavated areas
- Installation of silt fences and basins to capture sediment runoff along sloped areas
- Quick-growth seeding and geotextile placements to stabilize sod in staging areas

Onsite landfills for excavation or other remedies can employ evapotranspiration covers, which promote microbial degradation of waste while providing a substrate for plant growth.

BMPs for preserving ecological systems include:

- Avoiding tree removal in staging areas or intermittent uncontaminated zones, and retrieving and transplanting native, noninvasive plants
- Using non-chemical solarizing techniques for vegetative transplants or new plantings; non-synthetic fertilizers, herbicides, or pesticides; and integrated pest management methods
- Limiting noise and artificial lighting that disturbs sensitive species, and rescuing and relocating sensitive or threatened species

Many environmental, academic, and broad-based community groups offer assistance in ecological inventories as well as rescues.

Long-Term Stewardship Actions

Coordinated planning of remediation and anticipated use of a site is critical to long-term sustainability. Green remediation encourages decision-makers to weigh the environmental and economic tradeoffs of issues such as onsite versus offsite disposal of contaminated soil or sediment. Proper planning will help reduce likelihood of adverse impacts such as soil subsidence, unbalanced soil chemistry, or low microbial populations, and periodic post-excavation field tests will help identify unexpected problems quickly.

Prompt revegetation is critical to restoration of backfilled areas. Installation of native rather than imported plants will increase vegetation viability, avoid immediate- or long-term irrigation needs, and promote rapid ground cover. Plant diversity also will create useful wildlife habitat and more opportunities for future activities or site reuse.

Green Remediation: A Sampling of Success Measures for Excavation and Surface Restoration

- Reduced fuel consumption and transportation costs as a result of integrated "dig and haul" planning with fewer field mobilizations
- Reduced GHG emissions through use of renewable resources to provide electricity for auxiliary equipment or replace natural gas-driven equipment
- Increased volumes of graywater recycled or reused in sediment dewatering, in place of clean water
- Increased percentage of excavated clean soil or material that is reused onsite
- Higher percentage of ground cover sooner after excavation, with fewer invasive species
- Increased utility of "excavation built" erosion and stormwater controls in site reuse

Visit Green Remediation online to obtain more information about BMPs, view site-specific examples, or share new ideas about green cleanups.

http://cluin.org/greenremediation

United States Environmental Protection Agency
Office of Land and Emergency Management (5203P)
EPA 542-F-16-002
September 2016 Update

Green Remediation Best Management Practices: Site Investigation and Environmental Monitoring

A fact sheet about the concepts and tools for using best management practices to reduce the environmental footprint of activities associated with assessing or remediating contaminated sites

www.cluin.org/greenremediation

EPA's *Principles for Greener Cleanups* outline the Agency's policy for evaluating and minimizing the environmental footprint of activities involved in cleaning up contaminated sites.[1] Best management practices (BMPs) of green remediation involve specific activities to address the core elements of greener cleanups:

- Reduce total energy use and increase the percentage of energy from renewable resources.
- Reduce air pollutants and greenhouse gas emissions.
- Reduce water use and preserve water quality.
- Conserve material resources and reduce waste.
- Protect land and ecosystem services.

Overview

The need for site investigation is common to cleanups under any regulatory program. Investigative activities can occur at all points in the cleanup process, from initial site assessment through waste site closeout. A site investigation generally is undertaken to:

- Confirm the presence or absence of specific contaminants.
- Delineate the nature and extent of environmental contamination.
- Identify contaminant sources.
- Provide data for assessing potential risk to human health or the environment.
- Gather data for determining if a remedial or removal action should be taken.
- Identify site characteristics affecting remedial design, construction or operation.

Site investigation as well as long-term environmental monitoring typically involve a range of technologies and techniques to gather field measurements and collect analytical samples of soil and groundwater and often surface water, sediment, soil gas or indoor air. Investigation also may involve searching for underground storage tanks, drums or other buried objects, or evaluating demolition material containing asbestos, lead-based paint or other toxic products. Many of the same techniques and technologies may be used in later stages of a cleanup to evaluate ongoing performance of a remedy; determine the need for any modification to a remedial system; or track factors influencing anticipated closeout of a cleanup project. At certain points, site investigation and environmental monitoring both rely on data analysis or verification conducted by offsite laboratories.

Water monitoring at the New Idria Mercury Mine Superfund site in California involves use of time-interval sampling devices powered by solar energy. Collected sampling data are transmitted via satellite to a website accessible by project staff. This approach supplies a renewable source of onsite energy and reduces the frequency of staff visits to this remote site. Ongoing investigation of this site led to removal actions in 2011 and 2015.

Project Planning

Integration of green remediation BMPs early during the project design phase will help reduce cumulative environmental footprints of a cleanup. The BMP integration process involves selecting BMPs most suitable for the site's unique contamination scenario, potential remedies and anticipated site reuse. BMPs to be considered when planning a site investigation include:

- Schedule activities for suitable seasons to reduce the amount of fuel needed for heating or cooling equipment and supplies.
- Select service providers, product suppliers and analytical laboratories from the local area and consolidate the service and delivery schedules.

The ASTM *Standard Guide for Greener Cleanups* outlines a process for identifying, screening and selecting BMPs to minimize the environmental footprint of site-specific cleanup activities.[2]

- Identify local sources of trucks and machinery equipped with advanced emission controls and of cleaner alternative fuels.[3]
- Identify the nearest facility to be used for disposing of hazardous waste.
- Establish electronic networks for data transfers, team decisions and document preparation, and select electronic products through tools such as the Electronic Product Environmental Assessment Tool (EPEAT).[4]
- Reduce travel through increased teleconferencing and compressed work hours.
- Select facilities with green policies for worker accommodations and meetings.
- Integrate sources of onsite renewable energy to power hand-held devices, portable equipment, and stationery monitoring systems.

Product and service acquisitions provide opportunities to integrate BMPs when planning a site investigation. New contracts awarded by EPA for remediation environmental services at Superfund sites, for example, now require contractors to explore and implement strategies to reduce energy and water usage, promote carbon neutrality, promote industrial materials reuse and recycling, and protect and preserve land resources.[5]

Development of a well-conceived dynamic sampling plan can help assure that data truly representing a site are collected at the project onset, consequently minimizing remobilization of field crews and equipment. Systematic planning, which is a critical component of optimized strategies for investigating hazardous waste sites, involves identifying key decisions to be made, developing a conceptual site model (CSM) to support decision making, and evaluating decision uncertainty along with approaches for actively managing that uncertainty. The CSM combines analytical data with historical information to identify data gaps and allows for refinement as additional data become available.

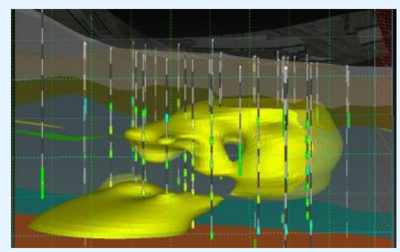
Field Activities

Fewer field mobilizations typically lead to reduced fuel consumption and associated air emissions and often less disturbance to the land and local ecosystems. BMPs that can help minimize mobilization during site investigation and environmental monitoring include:

- Use in situ data loggers to monitor water quality parameters and water levels, as an alternative to frequent sample collection or physical measurement.
- Install solar-powered telemetry systems to remotely transmit logging data.
- Use dynamic work plans involving real-time field measurements, which can immediately provide data to help determine the next activity during a given sampling event.

Technologies for collecting real-time data are typically non-invasive or minimally invasive; examples include:

- Direct sensing equipment such as the membrane interface probe, laser-induced or X-ray fluorescence sensors and cone penetration tests.
- Immunoassay, colorimetric and other field test kits to screen soil and groundwater contaminants.
- Portable vapor/gas detection systems using photoionization or flame ionization for screening purposes.
- Soil gas surveys involving instruments such as SUMMA canisters to determine the presence, composition and distribution of volatile organic compounds (VOCs) in the vadose zone and water table.
- Portable gas chromatography/mass spectrometry for analyzing fuel-related compounds and VOCs in soil and groundwater.
- Ground penetrating radar, magnetometers, and other geophysical survey instrumentation to locate metal objects and delineate disposal areas.



At Well 12A within the Commencement Bay-South Tacoma Channel Superfund site in Washington, high-resolution characterization data and 3D visualization were used to develop a robust CSM. The CSM helped quantify contaminant mass in soil and groundwater, delineate discrete treatment zones and prioritize remediation design approaches. This refined, minimally invasive strategy for site characterization significantly accelerated site cleanup, saving an estimated $1 million in treatment costs. Additionally, use of passive sampling devices for long-term monitoring avoided generation of purge water while saving more than $100,000 in the first five years of monitoring alone.

Other BMPs typically applying to site investigation and environmental monitoring focus on conserving and protecting water and using environmentally friendly products, such as:

- Deploy passive sampling devices, which involve no well purging.
- Use supplemental techniques to map the source and extent of a contaminated groundwater plume, such as analyzing core samples taken from rapid-growing trees.
- Employ a closed-loop graywater washing system to decontaminate trucks or machinery.
- Steam-clean or use phosphate-free detergents instead of organic solvents or acids to decontaminate sampling equipment.
- Use plastic sheeting or portable wash pads to contain and collect decontamination fluids and prevent their entrance into storm drains or groundwater.

- ♦ Treat potentially contaminated purge water through use of technologies such as activated carbon filtration prior to discharge to storm drains or waterways.
- ♦ Quickly restore disturbed areas of vegetation serving as stormwater controls.
- ♦ Use biodegradable lubricants and hydraulic fluids.
- ♦ Choose groundwater monitoring equipment made of noncorrosive material.

Yet other BMPs concern design and installation of groundwater wells to be used for sampling and monitoring. Relevant BMPs include:

- ♦ Design investigative wells in ways that allow for maximum reuse during remediation or to meet water demands of ongoing or future site activities.
- ♦ Integrate a horizontal well network where feasible as an alternative to a greater number of vertical wells.
- ♦ Choose a multi-port sampling system in wells intended for monitoring, to minimize the total number of wells needing to be installed.
- ♦ Use minimally invasive drilling techniques such as direct-push or sonic technology whenever feasible to reduce drilling duration, avoid or minimize use of water, and prevent or reduce generation of cuttings and associated disposal of investigation-derived waste (IDW).
- ♦ Use dual tube technology during drilling, which allows collection of continuous soil cores and later reuse of the same boreholes for site investigation, remediation or monitoring.
- ♦ Use an electric top drive system to minimize use of hydraulic fluids when rotary drills are used.
- ♦ Segregate and screen drill cuttings for potential use such as onsite backfill if allowed under applicable state or federal cleanup programs; use of an organic vaporizer analyzer may significantly improve or accelerate the screening process.
- ♦ Use environmentally friendly pipe dope for drill pipes and casings.
- ♦ Emplace mats to limit ground surface disturbance at drilling locations.

Use of passive diffusion bag (PDB) sampling techniques in 56 wells at the Joint Base Lewis McChord Superfund site in Washington significantly reduced the environmental footprint of sampling activities. When compared to using low-flow sampling techniques in other wells, PDB use achieved a:

- 54% reduction in energy used.
- 55% reduction in greenhouse gas emissions.
- 63% reduction in criteria pollutants.

The footprint reductions were driven by demonstrated reductions in the amount of field time, which leads to fewer vehicle miles traveled and associated fuel consumption. A two-person team was able to sample 12 of the wells per day when using PDBs but only five wells per day if using low-flow methods.[6]

Materials and Waste Management

Site investigation and environmental monitoring activities typically involve using an assortment of manufactured products such as personal protective equipment (PPE), sample containers and routine business materials. BMPs concerning green purchasing of such products include:

- ♦ Choose products with recycled and biobased contents such as agricultural or forestry waste instead of petroleum-based ingredients.
- ♦ Choose products, packing material and equipment that have reuse or recycling potential.
- ♦ Choose products manufactured through processes involving nontoxic chemical alternatives.

A comprehensive list of tools and resources for materials management decision-making is available in EPA's *Sustainable Materials Management in Site Cleanup* engineering issue paper.[7]

IDW generation and management frequently account for a significant portion of the environmental footprint of site investigation. IDW includes drill cuttings, well purge water, spent carbon from filtration equipment, reagents used with environmental field test kits, non-reusable or contaminated PPE and solutions for decontaminating non-disposable PPE and equipment. Reducing the volume of generated IDW will decrease the need for waste containers such as 55-gallon storage drums and for treating IDW onsite or disposing of it at a waste facility. Recommended BMPs to reduce the volume of routine waste or IDW, while often decreasing materials consumption, include:

- ♦ Compress the number of days needed for a given round of sampling.
- ♦ Minimize the need for disposable single-use items such as plastic bags.
- ♦ Designate collection points for items that are locally recyclable, such as metal, plastic or glass containers and paper or cardboard.
- ♦ Select test kits that generate less waste, such as soil samplers with reusable handles for coring syringes.
- ♦ Collect hydraulic fluids and lubricants for recycling at suitable local facilities.
- ♦ Maximize use of environmentally friendly additives such as ascorbic acid to preserve or stabilize collected samples, if compatible with target analytes and anticipated analytical methods.[10]

Use of EPA's *Spreadsheets for Environmental Analysis*[8] to estimate the footprint of cleanup activities at the Grants Chlorinated Solvents Plume Site indicated that laboratory analysis (including sample collection and preparation and offsite transport) accounted for approximately 10% of the energy- and carbon dioxide (equivalent)-related footprint of operating, maintaining and monitoring the remedy.[9] As a result, optimization of the sampling program is underway to reduce the frequency of sample collection and analysis.

Laboratory Support

Use of fixed-base laboratories for analytical services may significantly contribute to the environmental footprint of site investigation and environmental monitoring when considering offsite as well as onsite contributions. Green remediation BMPs concerning analytical support include:

- Use a mobile laboratory or portable analytical equipment, particularly for screening purposes and when rapid analytical results are needed.
- Specify EPA analytical methods involving procedures that need relatively low volumes of samples or solvents and generate less waste, such as solid phase micro extraction (SPME), pressurized fluid extraction, microwave extraction, and supercritical fluid extraction when possible. For example, SPME is a single-step process using little or no solvents and taking up to 70% less time.
- Choose fixed laboratories demonstrating a strong commitment to environmental performance, such as routine use of management practices identified by the International Institute for Sustainable Laboratories.[11]

Attributes of high-performing laboratories include:

- Optimized ventilation rates in light of the mixing factor of particular pollutants being removed from the laboratory; simply maximizing ventilation results in unnecessary energy expenditure (and may diminish safety conditions).
- Use of energy recovery devices and systems to reduce energy consumption for interior heating and cooling.
- Use of energy-efficient equipment for ventilation, refrigeration and lighting.
- Use of energy consumption controls such as programmable thermostats, window glass tinting and ample insulation.
- Cooling tower operation with a high concentration ratio, which increases the number of times water circulates before it is bled off and discharged; cooling accounts for an estimated 30-60% of water used in multipurpose laboratories.[12]
- Integration of solenoid valves, timers or other controls on equipment used in processes requiring flowing water.
- Use of less hazardous materials; for example, toluene may substitute for benzene as a solvent.
- Implementation of purchasing strategies and inventory controls that minimize disposal of excess materials.
- Recycling of liquid waste; for example, non-halogenated solvents may be used offsite as fuel blending feedstock.
- Recycling of materials such as clean glass or plastic containers, drums, electronics, and steel or aluminum instrumentation.

Acquisition of laboratory services supporting remedial investigation at the Diaz Chemical Corporation Superfund site in Holley, New York, included specifications meeting EPA greener cleanup policy. The selected laboratory employs practices such as:

- Recycling all paper products and shipping materials.
- Using energy-efficient lighting.
- Maintaining a paperless reporting and invoicing program.
- Minimizing waste through use of EPA-approved microscale methods.

Similar procurement requirements for subcontractor drilling activities reduced the investigative footprint by:

- Using direct-push technology.
- Deploying trucks equipped with advanced emission controls.
- Minimizing waste through waste oil and scrap recycling.

This fact sheet provides an update on information compiled in the December 2009 "Site Investigation" fact sheet (EPA 542-F-09-004), in collaboration with the Greener Cleanups Subcommittee of the EPA Technical Support Project's Engineering Forum.

To view BMP fact sheets on other topics, visit CLU-IN Green Remediation Focus: www.clu-in.org/greenremediation.

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United States
Environmental Protection Agency

Office of Solid Waste and
Emergency Response (5102G)

EPA 542-F-09-005
December 2009

Green Remediation Best Management Practices: Pump and Treat Technologies

Office of Superfund Remediation and Technology Innovation

Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outlines the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) recommended in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis, while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.[2]

Overview

Pump and treat (P&T) technology typically is selected in a cleanup remedy to hydraulically contain contamination and/or restore an aquifer to beneficial use. Opportunities to reduce the energy and environmental footprint of a P&T remedy, which are available during site characterization and the remedy selection, design, construction, and operation phases, rely on effective planning and continual re-evaluation of P&T operations. Options for reducing the footprint vary based on the site conditions and cleanup objectives as well as the configuration and components of a planned or existing P&T system. Effective footprint reduction activities will complement the cleanup objectives while aligning with related guidelines such as *Executive Order 13514: Federal Leadership in Environmental, Energy, and Economic Performance*.[3]

P&T remedies often operate for long periods, in some cases decades, due to the nature of the technology and the nature of contaminant transport in the subsurface. As a result, operation of a P&T system, compared to system construction, can contribute significantly to the energy and environmental footprint of a P&T remedy. The best opportunities typically relate to optimizing efficiency of long-term operations, particularly in terms of energy and other natural resource consumption.

Continuous motor operation under load (for pumps, blowers, and other machinery) during a 30-year period of operation uses over 240,000 kWh of electrical energy per motor horsepower or over 2.7 billion BTUs of energy per motor horsepower (hp). This amount of energy is equivalent to the electricity used by more than 22 homes over one year.

Illustration of a P&T system with a fairly complex treatment process indicates how a system relates to each of the five core elements of green remediation. Components in this example can be removed to focus on how a simpler P&T system could affect the environmental footprint during operations.

P&T Component	Examples of Environmental Effects During a Complex P&T Operation
Groundwater Extraction	▪ **Energy** use (and associated **air** emissions) caused by generating electricity from fossil fuels to power extraction pumps ▪ **Materials** use for well construction, maintenance, and rehabilitation ▪ Removal of contaminated **water** and protection of other groundwater ▪ Potential dewatering of wetlands and disrupting wetland **ecosystems** located near extraction wells
Process Equalization	▪ **Energy** use (and **air** emissions) for pumps used to adjust pressures among treatment components
Metals Removal (chemical addition, precipitation, settling, filtration, and solids handling)	▪ **Energy** use (and **air** emissions) for electricity operating mixer motors and filter feed or solids handling pumps ▪ **Materials** use from chemical addition ▪ **Waste** disposal from removed solids, such as metals or biosolids ▪ Infringement on **land** and **ecosystems** from landfill space for waste disposal
Air Stripping	▪ **Energy** use (and **air** emissions) for electricity to operate a blower ▪ **Materials** use for chemical cleaning of a stripping system
Off-Gas Treatment and *Granular Activated Carbon Filtration*	▪ **Energy** (and **air** emissions) for electricity to preheat off-gas prior to vapor treatment ▪ **Materials** and potential **waste** disposal for granular activated carbon
Effluent Tanks	▪ **Energy** use (and **air** emissions) for electricity to pump water across a multi-step treatment process
Discharge to Surface Water	▪ Net withdrawal of local groundwater resources when extracted **water** is discharged to surface water
Building Operations	▪ **Energy** use (and **air** emissions) for electricity to power lights, ventilate a building, and potentially provide heat
Long-Term Operation	▪ Affects on **land** use and the local community and long-term stewardship of **land** and nearby **ecosystems**

Designing a P&T System

Recommended green remediation BMPs for designing a P&T system are intended to: maximize opportunities to address different portions of a contaminant plume in unique ways; modify or reconfigure a system according to changes in a contaminant plume over time; and supplement the system with other remediation or auxiliary technologies to reduce the P&T burden as groundwater cleanup progresses and new products or processes become available. P&T system design planning relies on robust delineation of the contaminant plume and source area. Early planning can also include a renewable energy assessment to determine whether solar, wind, or other resources could meet all or part of the electricity demand of P&T opera-tions; in turn, results of that assessment could influence the P&T design.

Cleanup at the former Nebraska Ordnance Plant involves use of a 10-kW wind turbine to power groundwater circulation wells for air stripping and ultraviolet treatment.

A P&T system's rate of groundwater extraction, anticipated duration, and quality of influent and the site's treatment goals typically have the greatest affect on the environmental footprint of the system. Use of the BMPs for technology selection and system design can address these traditional factors and help project managers evaluate how the factors contribute to consumption of energy, water, and other natural resources or result in air emissions and waste generation through the life of a cleanup project. System designers should also consider the site's anticipated reuse, to identify potential approaches for combining the needed infrastructures and minimizing long-term land disturbance.

Extraction Rates

The rate of groundwater extraction for a P&T system directly impacts the system's energy and materials use and waste management options. Optimization of extraction rates typically begins with a thorough site investigation that enables accurate well placement and helps determine the suitable number of extraction wells. [For more information, see: *Green Remediation Best Management Practices: Site Investigation*.[4a]]

Best practices for determining the optimal rate of groundwater extraction include:

- Establish an appropriate target capture zone and thoroughly evaluate the groundwater extraction needed to provide complete capture
- Base the capture zone analyses and design on parameters of actual aquifer test data and consider the use of modeling (with appropriate input information) to design the extraction system
- Consider designing a network of extraction piping that initially provides a conservative hydraulic capacity for the planned treatment system (perhaps by increasing pipe size or laying additional pipe when a trench is open), which allows for future modular increases or decreases in the extraction rate and treatment modifications, if needed; for example, the footprint of placing an additional extraction pipe that ultimately may be unused may be significantly smaller than remobilizing at a later date or overpumping a smaller network for many years
- When continuous pumping is not needed to contain the plume, consider whether pulsed rather than continuous rates of pumping can maintain the rate of groundwater transfer and treatment needed to ensure a protective remedy; additional gains in energy conservation may be possible by pumping during off-peak utility periods
- Consider reinjecting treated water downgradient of the extraction system to flatten the hydraulic gradient in the vicinity of the extraction wells, increase the capture zone width near the extraction wells, and potentially reduce the overall extraction rate; hydrogeologic consultation is recommended to ensure that reinjection does not adversely affect extraction efficiency, and
- Consider diverting upgradient, uncontaminated groundwater around the contaminant plume to reduce the amount of water to be extracted; feasibility of groundwater diversion would likely involve evaluation of environmental tradeoffs such as disturbance to land, ecosystems, and subsurface hydraulic conditions.

Duration of Operations

BMPs to help reduce duration of full-scale P&T systems (and reduce cumulative energy consumption, chemical and material use, and waste disposal) rely on adequate site and contaminant plume characterization. This information also can help evaluate the potential for using other remedial technologies to remove all or part of a contaminant source, which could reduce the P&T load as well as duration. Project managers should consider approaches that use supplemental technologies without compromising cleanup progress, schedules, and goals. Approaches could include:

- Collecting information on appropriate use of monitored natural attenuation (MNA) for the diffuse portion of the plume, in conjunction with EPA's MNA guidance[5]
- Considering technologies that can operate in conjunction with P&T, such as in situ chemical oxidation, thermal remediation, or bioremediation in the source area, and
- Planning options for implementing a remediation "polishing" technology at a stage when contaminant concentrations are reduced to a target level.

Influent Water Quality

Typically, design of a P&T system's treatment process is significantly driven by the quality of influent water. Loading of a particular constituent affects the size or specifications of given treatment processes, such as sizing of an air stripper or the adsorption medium in an air stripping system. In addition, treatment of different types of constituents such as metals, ketones, and ammonia often need specific processes that may use significant quantities of energy and materials and can generate significant quantities of waste.

Project managers should carefully evaluate "nuisance" contaminant constituents such as iron and manganese, which can easily foul system components or lead to more complex treatment systems that may involve additional energy and resources. Depending on a number of factors such as concentrations and depth intervals of these constituents, portions of the contaminant plume might be more effectively treated with other technologies such as in situ chemical oxidation or in situ bioremediation. If the extracted water contains iron, manganese, or other similar metals, a range of options could effectively address these constituents in ways that produce a different footprint. Options typically include:

- More frequent cleaning of components
- Use of downstream equipment that is less prone to fouling
- Use of a sequestering agent
- Metals removal via chemical addition and precipitation, and
- Use of alternate discharge options.

Concentrations of chemicals of concern in system influent may unexpectedly change over time. Frequent monitoring and use of real-time methods for concentration measurement will help identify changes quickly and prepare for treatment modifications throughout the project life. Continued use of an unmodified system that has become oversized over time can be a major cause of inefficiency.

Green remediation strategies for P&T design also involve evaluation of the options for discharging treatment effluent. Discharge to surface water, reinjection to the subsurface, and discharge to a publicly owned treatment works (POTW) all may be subject to federal or state regulatory requirements. One particular option may allow the overall remedy to have a lower footprint than other options; for example, discharge to a POTW will involve additional energy, materials, and waste before water is finally discharged to surface water.

Primary Treatment Technology Alternatives

Project managers should consider life cycles (and environmental tradeoffs) of feasible treatment processes when designing an aboveground treatment process for extracted groundwater. Several different technologies exist for addressing the same compounds or class of compounds, and each technology will present unique advantages, disadvantages, and footprints at a specific site. For example, air stripping, granular activated carbon (GAC), advanced oxidation, and bioreactors can all remove or destroy volatile organic compounds. Air stripping or GAC may make the smallest environmental footprint for a majority of sites, but in some cases ultraviolet oxidation (UV/Ox) may be more effective and leave a smaller footprint despite its additional energy and chemical use.

In general, resource efficiencies can be gained by:

- Using more than one treatment technology (from both the effectiveness and environmental footprint perspective) for each aspect of the treatment train
- Planning for elimination of treatment train components that will become unnecessary as site conditions change, and
- Using a form of renewable energy or waste heat; solar thermal panels, combined heat and power, or water-source heat pumps can provide the needed heat, and heat exchangers enable reuse of heat rather than discharging it as part of the effluent.

Applications for solar thermal energy (which generally incur lower capital costs than photovoltaic systems) include heating, cooling, ventilation, hot water heating, or process heating.

Selection of Chemicals and Process Materials

Chemical and materials use can contribute significantly to the environmental footprint of a P&T system. BMPs regarding use of chemicals for ex situ groundwater treatment focus on selecting the optimal vendor, type of chemicals, and dosage.

- Attempt to obtain needed chemicals and materials from local manufacturers in order to avoid long-distance transport, or from manufacturers in regions where grid electricity has relatively low emission factors[6]
- Consider chemical and material disposal needs, including offsite disposal of hazardous waste
- Consider the resources consumed during manufacturing or processing of treatment chemicals
- Consider the potential for these chemicals or treatment byproducts to be present in treatment effluent and the potential effects of these chemicals on human health and the environment
- Conduct sufficient bench-scale tests to help optimize chemical dosage, which minimizes chemical use during treatment, and
- Provide containment around chemical storage and batching areas to contain leaks.

When running process water or air through filters or adsorption media:

- Use liquid filters that can be backwashed to avoid frequent disposal of disposable filters
- Consider benefits of pre-treatment or pre-filtering prior to use of adsorption media such as GAC so that media are replaced based on chemical loading rather than fouling caused by solids loading
- Weigh the footprint advantages and disadvantages of preheating vapors prior to treatment with vapor-phase GAC; for example, preheating can significantly reduce relative humidity (an efficiency deterrent) but increases the system's energy demand, and
- Consider the source materials used to generate treatment media; for example, GAC media used in adsorption units can consist of virgin or reactivated coal-based GAC or virgin coconut-based GAC.

Collection and Disposal of Treatment Waste

Green remediation strategies for P&T remedies also consider the options for waste management.

- Take advantage of opportunities for chemical salvaging and material reuse, including regenerating rather than disposing of GAC, identifying uses for precipitated metals solids, and identifying uses of recovered product (such as creosote recycling or energy generation)
- Reduce the frequency and tonnage of hauling process-derived solid waste by improving solids dewatering with a filter press or other technologies, particularly if the energy used for dewatering can be offset by renewable energy, and
- Use sequestering agents to keep a maximum amount of iron and manganese in solution, to prevent equipment fouling, rather than removing them and generating additional process waste.

Profile: GCL Tie and Treating Superfund Site
Sidney, NY

- *Conducted remedial system evaluation (RSE) of a P&T system extracting 78 gallons of groundwater per minute (gpm) and treating groundwater through green sand filtration (for manganese and iron removal), air stripping and liquid-phase GAC (for organic compounds), and vapor-phase GAC (for off-gas emissions)*
- *Derived RSE results suggesting discontinued pumping from the intermediate zone (where the contaminant plume appeared to decrease independently), which could decrease the extraction rate by 23% and reduce costs while continuing to meet cleanup goals and schedules*
- *Estimated that implementation of the modified pumping plan could: avoid generating 1,000 gallons of liquid, listed hazardous waste needing offsite disposal; reduce annual electricity use by 8,000 kWh/year; and reduce carbon dioxide (CO_2) emissions by 4.8 tons/year*
- *Derived an additional RSE suggestion to bypass the existing air stripper that had become oversized as conditions changed, which could reduce electricity use by 200,000 kWh/year and CO_2 emissions by 120 tons/year*

Effluent Management and Related Standards

Treatment processes are driven in part by relevant federal or state standards for water quality discharge and off-gas emissions. Project managers should consider:

- "Going beyond" compliance with water and air quality standards under federal or state mandates and permitted emission or discharge, to further reduce P&T footprints on local water and air quality; the extra steps may or may not involve additional resources, and
- Establishing project goals for natural/materials resource consumption and conservation, using Executive Order 13423 as a guideline;[7] for example, use renewable energy from onsite resources to meet at least 10% of the treatment system's energy demand, and recycle 100% of all routine waste such as paper or electronic equipment.

When evaluating potential methods of effluent discharge in light of environmental tradeoffs, options include:[8]

- Reinjection of treated groundwater to the subsurface, which can recharge an aquifer with valuable water and avoid the need to treat background constituents (but may involve additional site activities to prevent well fouling or installation of additional well galleries); reinjection is commonly viewed as an environmentally favorable option because it replenishes an aquifer

- Release to surface water or storm water systems; this option typically involves stringent discharge standards and substantial monitoring requirements and expedites transport of water out of the watershed
- Discharge to a POTW or other regional water treatment plant, which may allow more efficient offsite treatment of certain contaminants such as ketones and ammonia (but might involve additional pre-treatment steps or redundancy with the onsite treatment system); for some complex treatment streams, treatment by a POTW or other regional water treatment plant may be a more efficient use of resources than building and operating another onsite treatment plant, and
- Beneficial onsite reuse of treated water (such as for irrigation, dust control, and constructed wetlands) to reduce the overall capacity needed by the local water supply network; treated water also may be used as a substitute for potable water in some plant operations such as chemical batching, process cooling, and use of water-source heat pumps for heating and cooling.

Profile: Havertown PCP Site
Havertown, PA

- *Reassessed performance of an operating P&T system employing four recovery wells and an ex situ treatment process involving three 30-kW UV/Ox lamps, a peroxide destruction unit, and two GAC units*
- *Took two UV/Ox lamps offline, based on system assessment indicating changing contaminant parameters*
- *Reduced electricity consumption by at least 168,000 kWh per year, due to turning off two UV/Ox lamps*
- *Reduced emissions by approximately 105 tons of CO_2, 280 pounds of nitrogen oxides, and 1,500 pounds of sulfur oxides each year, based on eGRID (version 1.1 for Pennsylvania); smaller offsite footprints also can be attributed to the avoided cooling water and fuel-harvesting resources needed for electricity generation and intermediate power loss on the electric transmission grid*

Electricity Use

The recommended BMPs for efficient use of electricity in P&T systems are designed to closely examine the demands of pump and fan motors and auxiliary equipment on a site by site basis. Factors that can significantly affect electricity consumption (and vary considerably in terms of power demands) include the type of pump needed for a given application, pump efficiency, motor efficiency, pump loading, use of variable frequency drives (VFDs), pump and pipe conditions, and the available fuel blend. The needed power also ranges considerably (possibly from 0.5 hp to 100 hp) depending on other site-specific factors such as treatment flow rates, contaminant types, and treatment processes. Best practices for electricity conservation include:

- Sizing pumps, fans, and motors appropriately and using energy efficient motors (such as National Electrical Manufacturers Association Premium® labeled motors)
- Using gravity flow where feasible to reduce the number of pumps for water transfer after subsurface extraction
- Installing VFDs to set constant or variable flow rates rather than throttling flow with valves; in many applications VFDs can reduce a pump's energy demand up to 50% while avoiding damage to mechanical equipment
- Considering processing via batch flows, operating portions of the treatment process train during off-peak utility periods, and installing amp meters to evaluate consumption rates on a real-time basis
- Using air- or water-source heat pumps and natural gas, propane, or other fuels in place of electrical resistive heating whenever possible; regardless of the heat source, set thermostats to temperatures needed for freeze protection, especially when the system is operating unattended, and
- Routinely check for and correct leaks in compressed air lines or inefficient use of compressed air; air-operated pumps are often less efficient than electric pumps.

Detailed information on selecting and improving performance of motors, pumps, and fans, as well as guidelines for improving overall energy efficiency of plant operations, is available from the U.S. Department of Energy's Industrial Technologies Program.[9]

Annual Energy Consumption of a Common P&T System	
Extraction system employing five 1-hp pumps	40,000 kWh
Operation of a 1,500-square-foot P&T building occupied three days per week, with electrical resistive heating in winter	25,000 kWh
Aboveground process-water treatment by an air stripper fitted with a 5-hp blower	40,000 kWh
Air stripper off-gas emission treatment with vapor-phase GAC, and vapor preheating with a 2kW in-line heater	16,000 kWh
Data monitoring/processing	10,000 kW
Total annual electricity consumption	131,000 kWh
Carbon footprint equivalency:[10] 94 metric tons of CO_2	

Constructing a P&T System

BMPs being developed or already in place for the construction business sector can apply to construction of a P&T system. The practices focus on three categories of activities that can significantly reduce a construction project's footprint.

Stormwater Discharge Controls

The areal footprint of a P&T system with respect to stormwater runoff is typically small. Although impervious services are commonly limited to building roofs, parking areas, and access roads, stormwater runoff and associated erosion and sedimentation should be minimized. EPA's proposed effluent limitation guidelines and standards for construction activities provide examples of strategies for preventing or controlling sediment (and pollutant) movement at a site.[11] Efforts should be made to minimize continuous impervious surfaces unless they serve as a cap as part of a soil remedy; gravel roads, porous pavement, and separated impervious surfaces can be used for this purpose. Maximum vegetative cover across the site will also reduce stormwater runoff and soil erosion and provide wildlife habitat.

Green Structures and Housing for Aboveground Treatment Processes

P&T systems typically need a building to protect groundwater pumping equipment and house the aboveground components. Although the sizing of needed buildings varies considerably, construction of every building offers opportunities for resource efficiencies. Life cycle construction strategies for buildings generally account for factors such as deconstruction and materials reuse as well as anticipated use and maintenance. The recommended practices also relate to housing of individual components of the treatment equipment. Project managers should:

- Adapt practices and goals addressed in the Federal Green Construction Guide for Specifiers,[12] which addresses provisions relevant to Executive Order 13423, environmentally preferable purchasing, energy efficient products, and industry standards of other organizations such as ASTM International
- Borrow practices from the U.S. Green Building Council's LEED® rating system for new building construction;[13] related checklists and guidelines outline specific parameters and a range of tangible performance goals that apply to building siting, site preparation, water efficiency, energy efficiency and renewable energy, air protection, other natural resource protection, materials resources, and indoor air quality, and
- Attempt to locate treatment equipment in an existing building with existing utilities/infrastructure wherever feasible, but evaluate these buildings for potential efficiency upgrades; the footprint associated with operations could outweigh the footprint of construction.

Examples of green building methods for industrial purposes such as water treatment include:

- Consider using water-source heat pumps on treatment plant effluent, ground-source heat pumps, mobile waste-to-heat generators, or furnaces/air conditioners operating with recycled oil, to provide space heating and cooling
- Seal all process tanks and air duct systems to ensure adequate building ventilation for workers and to reduce energy loss, and install energy recovery ventilators to allow incoming fresh air while capturing energy from outgoing, conditioned air
- Insulate all pipes and equipment tied to treatment processes needing heat
- Maximize use of skylights for direct or indirect natural lighting of work areas
- Consider using high efficiency sprayers when equipment needs rinsing with fresh water
- Prevent damage to equipment through use of surge protection devices, and program the equipment to restart in phases to avoid additional power surges that trip circuit breakers, and
- Maintain all leak detection equipment and repair any leaking equipment in a timely fashion.

Fuel Consumption and Alternatives

Recommended practices for fuel conservation and related GHG reductions during construction of a P&T system focus on:

- Retrofitting engines to accommodate diesel emission controls or replacing obsolete engines; catalysts and filters should be verified by EPA or organizations such as the California Air Resources Board
- Conducting full and appropriate engine maintenance as recommended by manufacturers
- Limiting idling of fuel-powered vehicles, equipment, and machinery to a maximum of three minutes whenever possible; certain equipment such as drill rigs, however, commonly need longer idling times to maintain efficient work flow, and
- Switching to ultralow-sulfur diesel or biofuel meeting the ASTM D6751 standard, to reduce engine wear.

More information about fuel consumption and alternatives is available in: *Green Remediation Best Management Practices: Using Clean Fuel Technology in Site Cleanup.*[4b]

Operating and Monitoring a P&T System

Opportunities for resource efficiencies and conservation that are identified and planned during remedy design should be thoroughly documented to ensure that decision makers and operations contractors have sufficient information supporting decisions during operation and maintenance (O&M) and long-term groundwater monitoring. Potential documents for recording this information include cleanup contracts, feasibility studies, site management plans, and quality assurance project plans; for example, contracts could specify:

> *The contractor shall evaluate all reasonably feasible renewable energy sources when conducting work related to selecting a cleanup remedy, constructing a cleanup remedy, and when optimizing an existing cleanup remedy. Sources of renewable energy include solar, wind, and biomass and biogas.*

Other examples of contract language and procurement information are available in EPA's *Green Response and Remedial Action Contracting and Administrative Toolkit*.[14]

Best management practices for ongoing P&T operations address relatively routine activities as well as those promoting continuous improvements to system performance – the "check-do, recheck-redo" process. In particular, continual reassessment is needed to identify opportunities for downsizing the existing equipment or taking any equipment offline. Important activities for O&M and associated practices include:

- Periodically bench-scale testing alternative chemicals to determine whether changing groundwater parameters warrant different chemicals or when new products become available, and
- Re-evaluating potential for renewable energy sources as new technologies or financial incentives become available; one alternative may be purchasing renewable energy certificates that could extend to site reuse.

A photovoltaic system added to P&T operations at the Pemaco Superfund Site in Maywood, CA, contributes 5,900 kWh of electricity each year to high-vacuum dual-phase extraction of groundwater.

Equipment Maintenance

- Conduct manufacturer-recommended preventative maintenance of all processing and building equipment on schedule and conduct any needed repair in a timely fashion
- Automate mechanical and electronic equipment as much as possible and implement a telemetry system to reduce frequency of site visits and reduce extra late-night or weekend trips responding to alarms
- Employ an electronics stewardship plan that ensures purchases of EPEAT® and EnergyStar® products, power management for data centers, and recycling or reuse of expended electronic equipment or media
- Strive for fewer, longer days for O&M labor rather than more frequent, shorter days to reduce transportation to and from the site
- Identify suitable reuse for equipment no longer needed, and
- Check for any equipment that could be removed from continuous operation in the treatment train but retained for potential reintegration if needed.

Sampling and Analysis of Process Water

- Collect and analyze representative samples to ensure good process-related decisions, to avoid unnecessary resource consumption associated with unneeded sampling
- Maximize use of real-time measurement technologies such as sensors, probes, and meters to monitor processing conditions, and use program alarms to notify operators of any system or component failure
- Retain local laboratories or use an onsite laboratory program if possible to reduce the footprint associated with transportation of samples, and
- Request electronic deliverables to minimize materials and fuel consumption associated with hard-copy data reports, which also facilitates data sharing across team members.

Sampling and Analysis of Groundwater in Monitoring Wells

- Use long-term monitoring optimization approaches to eliminate redundant or otherwise unnecessary sampling; decision support tools such as monitoring and remediation optimization system (MAROS) software can be used to perform statistical trend analysis for optimizing sample locations, sampling frequency, and analytical parameters, and
- Minimize traffic and land disturbance during sampling through BMPs such as restricting traffic to confined corridors and protecting ground surfaces with biodegradable covers.

Profile: British Petroleum Site Paulsboro, NJ

- *Uses an onsite 275-kW solar field consisting of 5,800 photovoltaic modules to generate electricity for operating six recovery wells, including pump motors, aerators, and blowers*
- *Transfers extracted groundwater into a biologically activated carbon treatment system*
- *Generates 350,000 kWh of electricity each year through use of the solar field, which meets 20-25% of the P&T system's energy demand*
- *Eliminates emission of 571,000 pounds of CO_2, 1,600 pounds of sulfur dioxide, and 1,100 pounds of nitrogen dioxide each year through avoided consumption of fossil fuel-generated grid electricity*
- *Integrates ongoing groundwater cleanup with site reuse as a new port facility along the Delaware River, in partnership with state and local agencies; Port of Paulsboro operations are expected to generate $100 million annually in revenue and taxes*

Routine Checks and Balances

Making a P&T system more effective and efficient over time relies on awareness that site conditions, regulations, and technology options may change during the operating period and may differ significantly from those considered at the time of design.[15] As a result, one of the most significant BMPs for reducing the environmental footprints of a P&T system is to monitor these changes and periodically revisit these practices, perhaps on an annual basis, to identify appropriate system modifications. Standard operating procedures should include tracking of all electricity, natural gas, water, and materials consumption on a regular basis to identify any trends that may lead to increases in efficiency.

Green Remediation: A Sampling of Success Measures for P&T Operations[16]

- *Reduced electricity consumption and GHG emissions through use of energy efficient pumps and auxiliary equipment*
- *Increased percentage of electricity for groundwater extraction or aboveground treatment supplied by onsite renewable energy resources*
- *Reduced consumption of potable water due to substitution by treated water in chemical batching and cooling processes*
- *Reduced waste streams as a result of regenerating rather than disposing spent GAC and salvaging precipitated metals solids for offsite industrial use*
- *Beneficial reuse of treated water for restoration of onsite wetlands and ecosystems*
- *Reduced P&T loads due to integration of polishing technologies as contaminant concentrations decrease over time*

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Office of Solid Waste and
Emergency Response (5203P)

EPA 542-F-10-006
March 2010

Green Remediation Best Management Practices: Bioremediation

Office of Superfund Remediation and Technology Innovation

Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outlines the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) recommended in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis, while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.[2]

Overview

Bioremediation actively enhances the effects of naturally occurring biological processes that degrade contaminants in soil, sediment, and groundwater. In situ processes involve placement of amendments directly into contaminated media while ex situ processes transfer the media for treatment at or near ground surface. Green remediation BMPs for bioremediation address the techniques for:

- *Biostimulation*: injection of amendments into contaminated media to stimulate contaminant biodegradation by indigenous microbial populations. Amendments may include air (oxygen) by way of bioventing, oxygen-releasing compounds to keep an aquifer aerobic, or reducing agents such as carbon-rich vegetable oil or molasses to promote growth of anaerobic microbial populations
- *Bioaugmentation*: injection of native or non-native microbes to a contaminated area to aid contaminant biodegradation; successful bioaugmentation may involve prior addition of biostimulation amendments to create the conditions favorable for microbial activity
- *Land-based systems*: treatment of contaminated soil or sediment through surface mixing with amendments or placement of soil/sediment in surface piles or treatment cells, such as composting or landfarming, and
- *Bioreactors*: treatment of contaminated soil or groundwater in a controlled environment to optimize degradation, such as an in situ bioreactor landfill or biological permeable reactive barrier (biobarrier) or an ex situ batch- or continuous-feed reactor.

Designing a Bioremediation System

Early and integrated planning will help design a bioremediation project involving activities with a minimal environmental footprint. Effective design will provide flexibility for modified site or engineering parameters as cleanup progresses while continuing to accommodate current or future use of a site. Options for reducing the footprint of bioremediation implementation can be affected by local, state, and federal regulatory requirements. Permits for underground injections, for example, vary considerably among state regulatory programs.[3] Option evaluation also examines the short- and long-term advantages and disadvantages of in situ versus ex situ bioremediation techniques in terms of green remediation core elements.

Core Elements of Green Remediation

- *Reducing total energy use and increasing renewable energy use*
- *Reducing air pollutants and greenhouse gas emissions*
- *Reducing water use and negative impacts on water resources*
- *Improving materials management and waste reduction efforts, and*
- *Enhancing land management and ecosystem protection*

Successful bioremediation relies on adequate site characterization and development of a good conceptual model to assure thorough delineation of the contaminant source area(s) and plumes. Effective modeling will typically lower the potential for unnecessary activities and associated natural resource consumption or waste generation.[4a] Techniques such as three-dimensional imaging, for example, can help optimize placement of injection boreholes. Representative field data are needed during in situ bioremediation design to assure: (1) influential factors such as aquifer hydraulic conductivity, groundwater geochemistry, and soil heterogeneity and adsorptive capacity are well understood, (2) the radius of influence for any injected substrates reaches the entire target area and spacing of multiple injection points provides optimal substrate control, and (3) any excavation for techniques such as installation of a trenched biobarrier are conducted in a surgical manner.[4b]

Efficiency in energy and natural resource consumption can be achieved through BMPs that optimize initial design of a bioremediation system. Early bench-scale treatability tests on soil collected from the target treatment area will help:

- Determine the onsite mass of contaminant parent and daughter products, other metabolic products, and existing microbial populations

- Demonstrate specific biodegradation mechanisms of potential microbial cultures, chemical substrates, or amendments
- Evaluate potential delivery methods and dispersion characteristics under simulated aquifer conditions, including use of options such as biodegradable surfactants
- Select the most suitable reagents or amendments and optimal concentrations or proportions, and
- Determine any need for supplemental technologies to destroy contaminants in hot spots or areas anticipated to involve lengthy periods of microbial acclimation.

Profile: Bioaugmentation at MAG-1 Site, Fort Dix, NJ

- *Began bioaugmentation design through laboratory tests on MAG-1 groundwater samples to evaluate efficacy of a commercial bacterial culture in degrading targeted chlorinated volatile organic compounds (CVOCs) that were resistant to degradation by native bacteria*
- *Dispersed the microbial inoculant through a groundwater recirculation system, which minimized construction of new wells and associated resource consumption*
- *Optimized the system within six months of the first (of two) injections to reduce the initially high volume of buffering agents and extensive well fouling, resulting in reduced material consumption and equipment maintenance*
- *Decreased CVOCs nearly 99% within one year of project startup without negative impacts to natural groundwater conditions*

Natural resource efficiencies also are gained by conducting an onsite pilot test that evaluates methods for delivering the selected substrate or amendment to a portion of the treatment area. Green remediation BMPs applied during a bioremediation pilot test will help optimize full-scale operations and may identify adverse environmental impacts in the field; for example, improper addition of nutrients in certain aquatic environments could quickly cause algal blooms.

Use of innovative reagents from non-traditional sources can significantly reduce consumption of virgin natural resources while beneficially using various waste products. For instance, enzymes are often introduced into the remedial process to additionally stimulate microbial degradation of contaminants. These enzymes commonly exist in agricultural or industrial byproducts that may be readily available from local sources. One example is manure compost, which can provide various enzymes depending on the feedstock and maturity. Another byproduct gaining use for bioremediation purposes is spent-mushroom compost, which can be supplied at little or no cost by local producers. Evaluating potential use of products often considered to be waste will include examining the product's traditional fate and demand in markets other than site remediation.

Land-based systems and in situ bioreactors can particularly benefit from use of commercial waste. "Supermulch" contains common byproducts such as municipal biosolids, wood ash, and paper sludge that can be included in recipes for soil amendments or placed in a permeable reactive barrier to enhance activity of indigenous microbial populations. This approach can also be integrated with phytoremediation to encourage contaminant degradation and volatilization while enriching soil for revegetation in significantly disturbed areas such as mining sites.

Project designers can establish a schedule for periodic review of the selected bioremediation process and related decision points to:

- Determine if any improvements to field operations could reduce natural resource consumption and waste generation while maintaining bioremediation efficacy
- Identify any innovative materials that recently demonstrated success in biologically degrading contaminants while reducing the project's environmental footprint
- Identify unanticipated environmental impacts such as uncontrolled production of secondary byproducts, sub-optimal nutrient levels, or changes in non-targeted indigenous microbial populations, and
- Identify other processes that could accelerate biodegradation in certain areas without significantly increasing the project footprint; for example, some injection wells could be equipped with passive air flow-control devices and renewable energy-powered blowers to deliver air to the subsurface after bioaugmentation is conducted.

Future optimization may include introduction of alternate amendments to remediate portions of a site showing marginal biodegradation progress or alternate methods to increase efficiency of reagent delivery.

Integrated planning of bioremediation activities at Marine Corps Base Camp Lejeune enabled injections of emulsified vegetable oil and sodium lactate in four borings to be completed within only one week, which reduced field redeployment and associated fuel use.

Profile: Soil Composting at Former Joliet Army Ammunition Plant, Will County, IL

- *Conducted pilot-scale field tests on compost windrows to optimize the designed soil amendment recipe, amendment timing, loading rate, and turning frequency*
- *Constructed a 20-acre composting facility to treat 280,000 tons of excavated explosives-contaminated soil with amendments such as manure, wood chips, stable bedding, and spent biodigestor waste from local producers*
- *Installed a one-million-gallon basin to capture stormwater runoff for onsite aquifer infiltration*
- *Began early transfer of uncontaminated acreage to the U.S. Forest Service in 1997 to the newly formed Midewin National Tallgrass Prairie, with subsequent transfers of additional parcels as remediation progressed; by 2002, all (19,000) targeted acres were conveyed to the Prairie*
- *Completed soil cleanup in 2008, three years ahead of schedule, through implementation of an integrated cleanup and reuse plan for 3,000 acres now under development as business parks and an engineer training center*

Constructing a Bioremediation System

Best management practices initiated during bioremediation design can continue in the construction phase and during operation and maintenance (O&M). A significant portion of the environmental footprint left by construction of a bioremediation system involves the installation and testing of wells used to deliver the selected reagents and monitor performance. Recommended practices include:

- Using direct-push technology for constructing temporary or permanent wells rather than typical rotary methods, wherever feasible, to eliminate the need for disposal of cuttings and improve efficiency of substrate delivery into discrete vertical intervals
- Maximizing reuse of existing or new wells and boreholes for injections to avoid a range of wasted resources, and
- Using groundwater recirculation processes allowing multiple passes of groundwater through fewer wells.

Recommended practices for designing, constructing, and operating wells, such as those used for in situ injection and groundwater recirculation, are provided in: *Green Remediation Best Management Practices: Pump and Treat Technologies*.[4c] Additional practices for subsurface air delivery are provided in *Green Remediation Best Management Practices: Soil Vapor Extraction & Air Sparging*.[4d]

Project managers of land-based bioremediation systems can reduce the project footprint through BMPs such as:

- Constructing a retention pond within a bermed treatment area to store, treat, use, or release diverted stormwater
- Reclaiming clean or treated water from other site activities for use in injection slurries or as injection chase water
- Integrating a landfarm rain shield (such as a plastic tunnel) with rain barrels or a cistern to capture precipitation for potential onsite use, and
- Evaluating the need for a leachate collection system for a landfarm (along with a leachate treatment system) to fully preserve the quality of downgradient soil and groundwater.

Land disturbance during bioremediation construction, particularly at sites involving ex situ techniques, can be reduced through practices such as:

- Maintaining specific areas for different activities such as materials mixing or waste sorting, which will also avoid cross-contamination
- Covering ground surfaces of work areas with mulch to prevent soil compaction caused by activities such as front-loader application of soil amendments
- Establishing well-defined traffic patterns for onsite activities, and
- Employing rumble grates with a closed-loop graywater washing system (or an advanced, self-contained wheel-washing system) to minimize onsite and offsite trackout by delivery vehicles.

Emission of greenhouse gas (GHG) and particulate matter from mobile sources can be reduced through BMPs such as reducing engine idling, fueling heavy machinery with ultra low-sulfur diesel fuel, and retrofitting equipment with diesel oxidation catalysts or other advanced diesel technology. More practices are outlined in *Green Remediation Best Management Practices: Clean Fuel & Emission Technologies for Site Cleanup*.[4e]

Contributors to the Bioremediation Footprint at Romic East Palo Alto

	Total Estimated Footprint	Attributed to O&M
Energy	23,000 million Btu	58%
Potable water	6,800,000 gallons	100%
CO_2 equivalent	5,000,000 pounds	70%
Sulfur oxides	22,000 pounds	86%
Particulate matter	800 pounds	78%
Air toxics	200 pounds	10%

O&M activities account for much of the environmental footprint of bioremediation recently initiated at the Romic RCRA site in East Palo Alto, CA. Site investigation, remedy construction, and future decommissioning also contribute but to a lesser extent. Although onsite contributors are relatively small in comparison to offsite factors such as "upstream" materials manufacturing, they may hold greater importance to the local community.

Operating and Monitoring a System

Energy consumption and associated emissions during bioremediation O&M can be reduced by:

- Introducing biostimulation or bioaugmentation amendments to the subsurface via gravity feed in existing wells, when high-pressure injection is unnecessary to assure proper distribution in certain geologic units
- Evaluating feasibility of using pulsed rather than continuous injections when delivering air, to increase energy efficiency
- Employing portable units or trailers equipped with photovoltaic panels to generate electricity or direct power for equipment such as air blowers, and
- Investigating delivery of industrial byproducts needed in high volumes by way of rail rather than trucks.

Environmentally preferable purchasing in the context of bioremediation includes products such as:

- Tarps with recycled or biobased contents instead of virgin petroleum-based contents, for protection of ground surfaces in staging areas and coverage of soil undergoing ex situ treatment
- Soil nutrients and other treatment-related materials available in bulk quantities and packed in recyclable containers and drums, to reduce packaging waste
- Treatment liquids in concentrated form if a product is locally unavailable (and the concentration process does not involve additional energy consumption), to reduce long-distance shipping volumes and frequencies, and
- Biodegradable cleaning products effective in cold water applications, to conserve energy while avoiding introduction of toxic chemicals in environmental media.

Composting of mining waste-contaminated soil and sediment with municipal biosolids and lime along the Upper Arkansas River in Colorado resulted in 100% vegetative cover in most previously denuded areas within ten years, due to increased microbial functions combined with phytoremediation and reduced leachate.

Green remediation relies on continually improving a project's natural resource efficiencies and scouting for novel approaches. At the Distler Brickyard Superfund site in Kentucky, for example, chitin (a natural biopolymer derived from shrimp and crab shells) was injected into an aquifer as a source of volatile fatty acids to promote VOC degradation. Another example is provided at the Naval Amphibious Base Little Creek in Virginia, where bioremediation involved injection of diluted cyclodextrin (a simple sugar) that could be recycled. Information on reagent options and evaluation of related factors is provided in various demonstration reports compiled by the Environmental Security Technology Certification Program (ESTCP).[5]

Opportunities to reduce the environmental footprint of long-term actions can be further reduced through optimization of the monitoring program. Periodic reevaluation can help identify potential monitoring changes such as reduced sampling frequency, fewer sampling locations, or routine sampling of a smaller well network as a contaminant plume collapses over time.[6]

Green Remediation: A Sampling of Success Measures for a Bioremediation System

- *Reduced fuel consumption due to transport of high-bulk reagents via rail rather than trucks*
- *Reduced GHG emissions as a result of using gravity-fed injection systems rather than fuel-fed pumping*
- *Protection of nearby and downstream surface water through construction of bermed retention ponds that capture and treat contaminated stormwater runoff*
- *Beneficial use of industrial waste or surplus byproducts as bioremediation reagents*
- *Reduced soil compaction during system construction as a result of using well-defined work areas*

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- b *Excavation and Surface Restoration;* EPA 542-F-08-012, December 2008
- c *Pump and Treat Technologies*; EPA 542-F-09-005, December 2009
- d *Soil Vapor Extraction & Air Sparging;* EPA 542-F-10-007, March 2010
- e *Clean Fuel & Emission Technologies for Site Cleanup*; EPA 542-F-10-008, April 2010

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Emergency Response (5203P)

EPA 542-F-10-007
March 2010

Green Remediation Best Management Practices:
Soil Vapor Extraction & Air Sparging

Office of Superfund Remediation and Technology Innovation

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Overview

Historically, approximately one-quarter of Superfund source control projects have involved *soil vapor extraction* (SVE) to remove volatile organic compounds (VOCs) sorbed to soil in the unsaturated (vadose) zone. Air is extracted from, and sometimes injected into, the vadose zone to strip VOCs from the soil and transport the vapors to ex situ treatment systems for VOC destruction or recovery. SVE generally is used to:

- Remove a VOC source by controlling and diverting vapor migration from the source area(s) toward a point of compliance, and
- Remove vapors stripped from VOC-contaminated soil by other soil treatment methods such as electrical resistance heating at sites where the soil or contaminants are not amenable to SVE treatment alone.

Air sparging (AS) involves injection of air into contaminated groundwater to drive volatile and semivolatile contaminants into the overlying vadose zone through volatilization. SVE is commonly implemented in conjunction with air sparging to remove the generated vapor-phase contamination from the vadose zone.

In many cases, introduction of air to contaminated groundwater and vadose zone soils also enhances aerobic biodegradation of contaminants below and above the water table. Technologies such as bioventing or biosparging use active or passive air exchange processes similar to those used in SVE and AS but focus on stimulating natural biodegradation processes and removing contaminant mass through vapor extraction. Information about minimizing environmental footprints of these and other biological technologies is provided in a green remediation fact sheet specific to bioremediation.[3a]

SVE and air sparging rely on air exchange between the ground surface and subsurface to volatilize contaminants, while similar air-based technologies promote biodegradation of contaminants by microbial populations.

Many opportunities exist for reducing the footprints of SVE and AS implementation, which can: incur high rates of electricity and fuel consumption due to long-term operation and maintenance (O&M); release contaminant vapors through vertical short circuiting or incomplete treatment of offgases; and require offsite disposal of investigation and remedy construction wastes.

A Sampling of Electricity Consumed by SVE Components over Three Years	
Vacuum blower	108,000 kWh
Off-gas treatment system	90,000 kWh
Data monitoring and processing	33,000 kWh
Aboveground treatment structure	1,800 kWh
Total electricity consumption: 232,800 kWh	

Electricity consumption by typical SVE equipment operating for three years (excluding system design and construction) could emit 184 tons of carbon dioxide (based on the average U.S. fuel mix), which is equivalent to the electricity used by nearly 22 homes over one year.
[http://www.epa.gov/RDEE/energy-resources/calculator.html]

A green cleanup involving SVE or AS will:

- Reduce total energy use and increase renewable energy use
- Reduce air pollutants and greenhouse gas (GHG) emissions
- Reduce water use and negative impacts on water resources
- Improve materials management and waste reduction efforts, and
- Enhance land management and ecosystem protection.

Designing an SVE or AS System

Green remediation strategies for implementing SVE and AS rely on early development of a conceptual site model (CSM) that is refined as remedial activities progress. The CSM provides a tool to support selection of green remediation options, supply field data for decision-making, establish short- and long-term decision points, and document the changes in site conditions over time.

Soil-vapor flow models coupled with thorough delineation of source areas and vapor-phase plumes help optimize well locations and screen depths. The footprints of field data acquisition can be reduced through methods such as using field test kits wherever possible for soil sampling. Other best practices are described in a companion fact sheet specific to site investigations.[3b]

Optimizing the initial design of a vapor treatment system can result in efficient use of resources and placement of environmental safeguards.[4] Project managers can reduce energy consumption and related air emissions while conserving other natural resources through BMPs such as:

- Selecting vacuum pumps and blowers (including multiple low-flow blowers) that accommodate changes in operating requirements as treatment progresses
- Using piping of sufficient diameter to minimize pressure drops and resulting need for additional energy to operate blowers
- Using variable frequency drive motors to automatically adjust energy use to meet system demand
- Examining feasibility of using pulsed rather than continuous air exchange processes, which can also facilitate extraction of higher concentrations of contaminants
- Considering barometric pumping, which can use barometric pressure differences to enhance air throughput if adequate response lag exists between the subsurface and atmosphere
- Minimizing the size of the above-ground treatment system and equipment housing and using energy-efficient design elements such as passive lighting and exterior shading, to minimize heating and cooling needs
- Considering feasibility of increasing the number of AS venting wells to decrease the applied flow, in light of potential energy and materials tradeoffs associated with additional well construction and operations
- Planning for co-treatment of SVE vapors with offgases from other treatment systems, when concentrations allow, to gain efficiencies through economy of scale
- Establishing decision points triggering a change in the vapor treatment approach, such as switching from thermal oxidation to granular activated carbon (GAC) media; effective evaluation of alternate methods will consider tradeoffs such as potential increases in material consumption or waste generation, and
- Establishing decision points that could warrant transition from SVE to an alternate technology such as bioremediation.

Project managers can also identify processes in which renewable energy resources can be used as a power source for air transfer, vapor treatment, and field activities. Solar energy could be used, for example, to provide the energy needed for separating oxygen from ambient air when introduction of pure oxygen rather than air is warranted for AS without SVE.

Profile: Former Ferdula Landfill
Ferdula, New York

- *Designed an innovative SVE system to vacuum landfill gas through exclusive use of wind energy*
- *Installed a single windmill to provide direct power for the vapor extraction wells and equipment for GAC treatment of extracted vapor*
- *Confined all extraction and treatment equipment in a 150-foot^2 building located next to the windmill*
- *Used a pulsed vacuum process that optimized treatment rates while allowing for full off-grid operations and intermittent wind conditions*
- *Optimized windmill design through use of aluminum blades and a steel roller (instead of conventional steel blades and bronze roller bearings) to improve performance at wind speeds below 5 mph*
- *Continuously monitored system operations through use of a remote data collection system*
- *Extracted nearly 1,600 pounds of total VOC mass to date, over 7 years of operations*
- *Expended $14,000 for wind system installation at project startup but avoiding $15,000 in annual electricity expenses*

Use of horizontal vapor extraction wells can help minimize upwelling caused by vacuum extraction in areas of shallow groundwater and may improve overall efficiency of air extraction. In cases where groundwater pumping is needed to sufficiently depress the water table and prevent upwelling, groundwater may be reinjected downgradient of the treatment system to recharge the aquifer or, if needed, treated above ground and then reinjected.

An onsite pilot test is recommended to:

- Assure suitable sizing of equipment to be used in adding or withdrawing air to or from the subsurface, which will optimize energy use
- Determine the minimum air flow rate that can meet the cleanup objectives and schedule while minimizing energy consumption
- Evaluate the efficacy of air/vapor treatment, to identify any opportunity for reduced material use or waste generation, and
- Establish a project baseline on information such as electricity and water consumption, volumes of material purchases, and offsite disposal volumes, which can be used to identify, implement, and measure continuous improvements to an operating system and identify opportunities for modifications resulting in major efficiency gains.

Generation of SVE and AS material waste and wastewater relates primarily to ex situ treatment of vapors. Roughly 70% of Superfund SVE systems have used GAC treatment and approximately 25% have used thermal or catalytic oxidation. Wastes potentially needing offsite treatment and disposal include spent non-regenerable carbon canisters or liquid condensate from air/water separators. Treatment designs can include plans to:

- Treat condensate in onsite systems where contaminant types and concentrations permit
- Recycle condenser water as supplemental cooling water where concentrations permit
- Reclaim uncontaminated pumped water and treated groundwater for onsite use such as dust control, vegetation irrigation, or process input for other treatment systems, or
- Avoid or minimize dewatering when lowering of the water table is unneeded to treat the smear zone or otherwise unnecessary, by reducing the applied vacuum or installing additional extraction vents.

Design options for reducing the footprint of SVE or AS also may involve system integration with other cleanup technologies and evaluation of associated environmental tradeoffs. Heat application through electrical resistance heating or steam injections, for example, can mobilize contaminants for subsequent capture by an SVE system. This integrated approach may reduce treatment duration but is likely to increase the remedial system's net energy demand. Similarly, an SVE system design could incorporate dual phase extraction technology to more efficiently remediate capillary fringe areas consisting of low permeability soil but at the expense of additional energy input.

Efficiencies also can be gained through acquisition of green goods and services. Green remediation tools in EPA's ***Green Response and Remedial Action Contracting and Administrative Toolkit*** *include sample contract language and reporting structures for key issues such as energy use.*[5]

Constructing an SVE or AS System

A significant portion of the environmental footprint left by construction of an SVE system involves well installation. The greatest opportunities for reducing this footprint contribution relate to gaining fuel efficiencies, reducing drilling waste, and minimizing land and ecosystem disturbance. Direct-push technology (DPT), for example, can be used to install standard 2-inch diameter vacuum extraction wells, air injection wells, groundwater depression wells, and monitoring points. Use of DPT equipment rather than conventional drilling rigs can:

- Eliminate drill cuttings and associated waste disposal
- Avoid consumption or disposal of drilling fluids, and
- Reduce drilling duration by as much as 50-60%.

Evaluating the options for well construction can also include consideration of potential environmental tradeoffs. In the case of using DPT, for example, its deployment ease can reduce fuel-intensive field activities; however, attempted DPT use at depths approaching the technology's typical limit (100 feet) could result in wasted fuel or well installation failure. Another example is the use of small-diameter injection wells that can lead to large pressure drops and increase energy consumption of the system. Additional practices for well construction are provided in a companion green remediation fact sheet on remedies using pump and treat technology.[3c]

Emission of GHG and particulate matter from trucks and other mobile sources during SVE/AS system construction can be reduced through use of BMPs such as retrofitting equipment for cleaner engine exhaust, using ultra low-sulfur diesel, and reducing idling. More practices are outlined in *Green Remediation Best Management Practices: Clean Fuel & Emission Technologies for Site Cleanup*.[3d]

O&M costs at the former Ferdula landfill site average below $500 annually, in contrast to an estimated $75,000 per year for materials, electricity, and other resources needed for a conventional SVE system meeting the same remedial goals.

Operating and Monitoring an SVE or AS

SVE and AS system operations can generate high levels of noise. Adverse impacts on wildlife and local communities can be reduced prior to system startup through integration of aboveground equipment housing that contains sound-proofing material. Acoustic barriers with recycled or recyclable components may be constructed onsite or obtained commercially. Use of centrifugal blowers rather than positive displacement blowers and installation of air-line mufflers also will decrease noise levels. Other best practices for preserving vegetation and wildlife habitat include limiting the removal of trees that obstruct construction of the extraction or treatment systems and transplanting any shrubs from proposed extraction points to other onsite locations.

Additional reductions in land or ecosystem disturbance and efficiencies can be gained by early consideration of the site's anticipated reuse. For example, an SVE or AS pipe network could be constructed in ways allowing for future integration into the site's utility infrastructure. A companion fact sheet on excavation and surface restoration provides more examples of recommended practices as they relate to each core element of green remediation.[3e]

Recommended BMPs for O&M of an SVE or AS system focus on preserving air quality and reducing energy use, unnecessary material consumption, and excess waste generation. Inefficiencies often relate to release of contaminant vapors through vertical short circuiting, incomplete treatment of offgases, or migration of vapors beyond the treatment zone. Unintended vapor emissions or system inefficiencies can be reduced by:

- Adding a low-permeability soil cap at an area with negative pressure to prevent intrusion of clean air that can short circuit the extraction system; this option considers the environmental tradeoffs associated with cap construction and long-term presence of impermeable materials such as asphalt or concrete
- Ensuring that the zone of influence of vapor extraction wells completely covers the treatment area
- Installing and properly maintaining surface seals around all wells and monitoring points
- Maintaining flow rates sufficient to prevent vapors from migrating beyond the treatment area without overloading the treatment system
- Using vapor treatment methods appropriate for the influent vapor concentrations and changing the method as treatment progresses, and
- Regenerating adsorbtive media such as GAC filters.

SVE treatment typically results in an initially high contaminant loading that decreases over time, prompting the need for frequent system modifications. Good and flexible design will reduce needs for modification as site cleanup advances. Initial deployment of multiple smaller blowers, for example, can allow some blowers to be shut down when lower rates of air flow are found to continue meeting the cleanup objectives. Periodic remedial system evaluation (RSE) can help identify other system modifications to increase performance and efficiency, such as:

- Adjusting flow rates to obtain the minimum air flow and maximum amount of contaminants per volume of vapor removed
- Determining if any well in a manifold system is not contributing contaminants despite proper well functioning, and if so, modifying the well or taking it offline, and
- Operating pulsed pumping during off-peak hours of electrical demand, without compromising cleanup progress.

Once the bulk of contamination is removed, significant efficiencies can be gained by switching to a remediation "polishing" technology with lower energy intensity. One polishing option is passive SVE, which can be implemented by installing one-way check valves in well casings to promote barometric pumping. Environmental tradeoffs of using passive SVE on a large-scale basis may involve construction of additional wells.

Decreases in the frequency of field visits and associated fuel and material consumption or waste generation during system monitoring can be achieved by:

- Increasing automation through use of equipment such as electronic pressure transducers and thermo-couples with an automatic data logger (rather than manual readings) to record data at frequent intervals
- Using field test kits or analyzing for only indicator compounds whenever possible, and
- Reducing monitoring frequency and intensity once the system is optimized.

When a vapor extraction/treatment system is no longer needed, wells must be properly abandoned and system elements must be properly decommissioned. System close-out can include transferring any mobile treatment or monitoring units to other sites for reuse.

Green Remediation: A Sampling of Success Measures for SVE or AS Operations

- *Reduced electricity consumption through pulsed rather than continuous air delivery*
- *Decreased fugitive emission of contaminated vapor due to properly maintained well seals*
- *Lower need for potable water as a result of recycling condenser water for use in supplemental cooling*
- *Reduced material consumption and waste generation due to GAC filter regeneration*
- *Reduced noise disturbance to wildlife and communities through use of sound-proofed equipment housing*

References [Web accessed: 2010, February 28]

[1] U.S. EPA; *Principles for Greener Cleanups*; August 27, 2009; http://www.epa.gov/oswer/greencleanups

[2] U.S. EPA; *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites*; EPA 542-R-08-002; April 2008

[3] U.S. EPA; *Green Remediation Best Management Practices:*

[a] *Bioremediation;* EPA 542-F-10-006, March 2010

[b] *Site Investigation;* EPA 542-F-09-004, December 2009

[c] *Pump and Treat Technologies;* EPA 542-F-09-005, December 2009

[d] *Clean Fuel & Emission Technologies for Site Cleanup;* EPA 542-F-10-008, April 2010

[e] *Excavation and Surface Restoration;* EPA 542-F-08-012, December 2008

[4] U.S. EPA; *Off-Gas Treatment Technologies for Soil Vapor Extraction Systems: State of the Practice*; EPA-542-R-05-028, March 2006

[5] U.S. EPA OSWER/OSRTI; *Green Response and Remedial Action Contracting and Administrative Toolkit;* http://www.cluin.org/greenremediation/docs/Green_RR_Action_Contract_Admn_Toolkit_July2009.pdf

Visit *Green Remediation Focus* online:
http://cluin.org/greenremediation

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United States
Environmental Protection Agency

Office of Solid Waste and
Emergency Response (5102G)

EPA 542-F-10-008
August 2010

Green Remediation Best Management Practices:
Clean Fuel & Emission Technologies for Site Cleanup

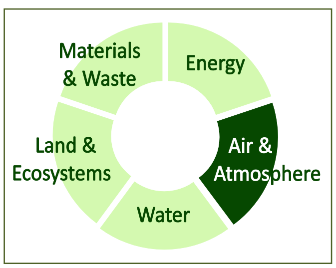
Office of Superfund Remediation and Technology Innovation

Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outlines the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) recommended in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis, while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.[2]

Overview

Cleanup of hazardous waste sites can involve significant consumption of gasoline, diesel, or other fuels by mobile and stationary sources. Minimizing emission of air pollutants such as greenhouse gases (GHGs) and particulate matter (PM) resulting from cleanup activities, including those needing fossil or alternative fuel, is a core element of green remediation strategies. Efforts to reduce these emissions during site investigation, remedial or corrective actions, and long-term operation and maintenance (O&M) must meet Clean Air Act (CAA) requirements and state air quality standards as well as requirements of federal and state cleanup programs.



Deployment of green remediation BMPs can help reduce negative impacts of cleanup activities on public health and the environment. The CAA currently specifies nitrogen dioxide (NO_2), ozone, lead, carbon monoxide (CO), sulfur dioxide (SO_2), and PM as the nation's criteria air pollutants. EPA's air quality criteria and national ambient air quality standards (NAAQS) for criteria pollutants must be met in all state implementation plans.

The Agency has studied impacts of six key GHGs in the atmosphere: carbon dioxide (CO_2), methane, nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Studies found that emissions of these GHGs from new motor vehicles and new motor vehicle engines contribute to GHG pollution threatening public health and welfare.[3]

The Centers for Disease Control and Prevention and EPA have identified numerous risks posed by the direct inhalation of toxic air particles and by wet or dry deposition of acidic pollutants (smog) released during fossil fuel burning.[4]

Health Effects

- Respiratory problems such as coughs or breathing difficulty
- Decreased lung function and increased susceptibility to respiratory infection
- Aggravated asthma and chronic bronchitis
- Arrhythmia and heart attack

Environmental Effects

- Increased smog (and reduced visibility) primarily due to increased ground-level ozone that oxidizes other pollutant gases such as SO_2
- Acidification of lakes and streams
- Nutrient imbalance in coastal waters and river basins
- Nutrient depletion in soil and toxic deposition on soil
- Damage to sensitive forests and farm crops
- Decreased populations and diversity of fish and other aquatic animals and plants
- Corrosion of stone (and man-made materials or structures)

Opportunities for reducing emission of air pollutants from *internal combustion engines in vehicles and stationary sources* used during remedy construction and implementation include maximizing use of:

- *Effective operations and maintenance* to assure efficiency of vehicles and field equipment *[page 1]*
- *Advanced diesel technologies* *[page 4]*
- *Alternative fuels and fuel additives* *[page 6]*, and
- *Fuel efficient and alternative vehicles* *[page 8]*.

Operations and Maintenance

Strategies for reducing unneeded engine use and fuel consumption (and associated air emissions) on a routine basis can be incorporated into site management plans, transportation plans, procurement documents for cleanup services or products, and internal training programs. The strategies focus on engine idle reduction, preventive maintenance to ensure peak operating efficiency, changes in daily routines, and effective fleet management.

Idle Reduction

Long duration idling consumes over one billion gallons of fuel annually in the United States, at a cost of over $2.5 billion. Idling of trucks, alone, is estimated to emit 11 million tons of CO_2, 180,000 tons of nitrogen oxides (NOx), and 5,000 tons of fine PM each year. A single hour of truck engine idling consumes approximately one gallon of fuel and emits approximately 20 pounds of CO_2. Idling also:

- Shortens engine service life
- Poses health and safety risks to vehicle and cab occupants in the event of emission leaks, and
- Increases pollution and noise in nearby communities.

Idling often occurs during site cleanup when loading or unloading materials, operating auxiliary equipment, and cooling or heating the interior of a vehicle or cab. A "no idling" policy can be implemented through corporate policy and onsite signage that displays idling time requirements meeting or exceeding those of state or local agencies.

EPA recommends idle reduction plans that include use of mobile on-board technologies such as:

- Automatic shut-down devices programmed to cut an engine after a predetermined time limit such as three minutes, unless engine operation is needed for intermittent activities such as well drilling
- Direct-fired heaters consuming only small amounts of a vehicle's diesel supply, which will eliminate the need for idling to warm the engine or cab interior
- Auxiliary power units or generators to provide power for certain activities, and
- Battery or alternative powered units to provide heating or air conditioning of cabs.

Other onboard technologies include commercial micro-solar units, which can be tailored to operate equipment traditionally relying on engine idling that provides battery power. An inexpensive 5-watt photovoltaic panel, for example, can be installed below the rear window of a passenger car and connected directly to a vehicle's battery to power local communications or radios.

Solar-powered telecommunications and video display systems can be installed in cab bulkheads, for easy access to site maps without a need for engine idle.

Use of off-board technologies for engine idle reduction can help reduce offsite as well as onsite footprints of a cleanup project. Long-distance haulers of outgoing waste or incoming supplies, for example, can periodically recharge various types of equipment at electrified parking spaces connected to a stationary electrical grid.

Equipment Maintenance

Green remediation strategies rely on maximizing equipment efficiencies of many site activities. Often overlooked efficiencies in fuel conservation can be gained through proper use and maintenance of all vehicles and equipment.

Transporters and field workers should ensure proper inflation and maintenance of tires at all times. Rolling resistance, an indicator of a tire's fuel efficiency, differs from tire to tire. Under-inflated tires increase the rolling resistance of vehicles and, correspondingly, decrease their fuel economy. Tire pressure monitoring systems on new vehicles are not a substitute for proper tire maintenance.

Decisions regarding tire purchases are expected to soon become more informed. In March 2010, the U.S. Department of Transportation (DOT) established test procedures to be used by tire manufacturers in a new consumer information program that generates comparative performance information for tire replacement. When fully implemented, the program will provide point-of-sale and online information (including a rating system) on fuel efficiency, safety, and durability of passenger car tires.

EPA recommends instituting vehicle and equipment maintenance plans that assure:

- Engine tune-ups in accordance with manufacturer recommendations, including optimal frequency
- Absence of dirt or insects in the fuel tank or line
- Tight connections and well lubricated moving parts
- Periodic replacement of filters in air and fuel systems
- Use of the manufacturer's recommended grade of motor oil, which can impact fuel economy up to 2%, and
- Effective operation of equipment ballast to keep wheels from slipping.

Project managers also need to plan periodic "housekeeping" of onsite fuel storage tanks to assure:

- Minimal contact between the fuel and water; every tank should be emptied periodically to remove any water from the tank bottom
- Sampling and testing of any standing water in tanks to determine existence of microbial populations; microbial organisms can degrade fuel (particularly biodiesel) and cause plugging in dispensers and vehicle fuel filters, and
- Addition of biocides for both conventional and biodiesel fuels wherever biological growth in the fuel has been a problem; biocides used with diesel fuels work equally well with biodiesel.

Stationary sources (or point sources) of air pollutants caused by fuel use during cleanup primarily involve the onsite facilities that operate ex situ groundwater, soil, or sediment treatment systems and the onsite equipment used to generate power. Components of many treatment systems may be powered by fuel such as diesel, gasoline, and propane or by electricity generated onsite from fossil fuels.

Facilities typically are required to install state-of-the-art pollution controls to prevent degradation of ambient air quality in areas that have achieved the NAAQS or to install the most protective pollution controls to help an area meet the NAAQS. Particularly in non-attainment areas, hazardous waste site cleanups should minimize negative impacts on minority populations, low-income populations, and sensitive subpopulations.

Pending the issuance of regulations and guidance on stationary diesel engines, EPA encourages project managers to take steps to reduce emissions from non-mobile diesel equipment.[5] Significant fuel and air emission reductions during site cleanup can be gained by properly maintaining and retrofitting diesel-fueled compression engines in equipment such as pumps, blowers, and air compressors or diesel-powered electricity generators. The California Air Resources Board (CARB) list of verified diesel emission control strategies includes control devices applicable to small stationary engines.[6]

Additional opportunities for reducing air emissions from stationary sources include:

- Replacing gasoline engines with ones powered by diesel, which is more powerful and 30-35% more fuel efficient
- Using solar or wind energy resources instead of diesel to generate electricity for operating small equipment such as groundwater circulation pumps, and
- Considering hydrogen and fuel cell generators in emergencies; fuel cell power generators relying on newly developed dry fuel cartridges also can be used in long-term support systems such as telecommunications.

Cleanup equipment should be reassessed on a frequent basis to determine when to replace equipment as a result of age or availability of advanced technologies. Public/private grants or incentives may be available to offset these engine repower (replacement) costs. Frequent reassessment also helps identify opportunities for equipment downsizing to reduce fuel use as site conditions change. Green remediation BMPs specific to remedies involving pump and treat technology, bioremediation, soil vapor extraction or air sparging, and other commonly used cleanup technologies are described in companion fact sheets available from EPA's Office of Solid Waste and Emergency Response (OSWER).[7]

Daily Routines

Transportation plans developed during remedial action planning should evaluate anticipated fuel use and specify strategies to minimize fuel consumption through efficient transportation routes, transfer of only full loads, and selection of appropriately sized vehicles for the task at hand. Using an undersized excavator for contaminated soil removal, for example, may extend cleanup duration and ultimately use more fuel, increase air emissions, and increase project costs. Similarly, use of an oversized truck to transport a small amount of hazardous waste to an offsite disposal facility would result in wasted fuel.

Site management plans should include BMPs to protect land surfaces and manage or minimize waste during cleanup, such as:

- Selecting high-quality equipment lubricants made of biodegradable ingredients such as food-grade grease and canola-based hydraulic fluid; associated purchasing costs are typically higher than petroleum-based oil but lower than synthetic products

Adding retrofitting devices such as a lean NOx catalyst and a diesel particulate filter could reduce these emissions by as much as 25% for NOx and 90% for PM.

Diesel Consumption in an Illustrative Excavation and Soil Amendment Project	Diesel Consumption (gallons)	PM Emission (pounds)[a]	NOx Emission (pounds)[a]	CO_2 Emission (tons)[a]
Removing contaminated soil through use of an earth mover with a 1990 200-hp engine operating for 100 days	6,400	100	1,100	70
Hauling 35,000 yd^3 of excavated soil to an offsite waste disposal facility 300 miles away, by way of 60-yd^3, 425-hp tractor trailers[b]	77,000	770	10,970	850
Importing wood milling and agricultural waste from sources 50 miles away, by way of a 60-yd^3, 300-hp truck[b]	2,400	100	1400	30
Applying 2,000 tons of soil amendments over 20 acres, using a 1990 290-hp, 60-yd^3 dump truck and 1990 170-hp grader	260	8	1	3
Using two medium-duty pickup trucks for site preparation and remedy construction over six months[b]	380	7	170	4
Total diesel consumption and air emissions (a) Diesel Emissions Quantifier; http://cfpub.epa.gov/quantifier/view/welcome.cfm (b) including use of ultra low-sulfur diesel, as required for on-road applications	**86,440 gallons**	**985 pounds**	**13,641 pounds**	**957 tons**

- Cleaning up any spilled fuels immediately to avoid damage to vehicles or engine bodies, inadvertent removal of safety decals, and seepage to soil or water
- Handling all materials used to absorb fuel spills in accordance with health and safety requirements and storing the material in noncombustible containers, and
- Properly disposing or recycling spent materials or liquid waste such as tires, transmission or brake fluids, used oil and filters, wash-rack waste, coolant, and spent solvent.

Efficiencies can be gained through better planning and combining of onsite or offsite trips to reduce overall mileage traveled and by avoiding "cold starts" that use more fuel. Simple changes in driving techniques can also improve fuel economy:

- Avoid rapid acceleration, braking, and excessive speeds, which can lower gas mileage as much as 30% on highways
- Learn the speed limit for optimal economy of specific vehicles; each 5-mph speed increment above 60-mph highway travel can be equivalent to paying an additional $0.24 at the gasoline pump
- Remove unneeded items in a vehicle; each 100 pounds of extra weight can reduce gas mileage up to 2%, and
- Use overdrive gearing to reduce an engine's speed, which in turn reduces engine wear.

Vehicle Fleets

The Energy Independence and Security Act of 2007 requires federal agencies to achieve a 20% reduction in fleet consumption of petroleum and 10% annual increase in fleet consumption of alternative fuel by 2015, as compared to a 2005 baseline. These goals can be achieved through measures such as substitution of cars for light trucks, an increase in vehicle load factors, a decrease in vehicle miles traveled, and a decrease in fleet size. Some states require reductions in fossil fuel use and GHG generation that exceed these federal targets.

Executive Order (E.O.) 13514 of October 2009 requires federal agencies to develop and implement innovative policies and practices for reducing GHG emissions, including GHG planning, reporting, and accounting procedures. EPA recommends that plans for operating vehicle fleets used for site cleanup emulate the fuel conservation strategies of E.O. 13514, which focus on:

- Using low GHG-emitting vehicles such as alternative fuel vehicles
- Optimizing the number of vehicles in a fleet, and
- Reducing the total consumption of petroleum products by fleets (of greater than 20 vehicles) by a minimum of 2% annually through 2020, relative to a 2005 baseline.

E.O. 13514 prohibits federal fleets from acquiring vehicles that are not low GHG-emitting vehicles and uses GHG reduction strategies such as:

- Incorporating incentives to reduce GHG emissions through changes in utility or delivery services, modes of transportation, or other supply chain activities
- Implementing strategies and accommodations for transit, travel, training, and conferencing that actively support lower-carbon commuting and travel by workers, and
- Working with vendors and service contractors to obtain information for tracking and reducing "scope 3" GHG emissions, which apply to sources not owned or directly controlled by an agency but relating to agency activities.

Influential factors affecting GHG emission include hours of equipment use, load factor, fuel consumption, density conversion, emission factors, and engine horsepower/tier level. Tracking and reporting of GHG and criteria pollutants during site cleanup can be simplified by new commercial or government-sponsored software as well as services offered by equipment rental organizations. EPA offers several planning tools, including the:

- Motor Vehicle Emission Simulator (MOVES) to predict gram-per-mile emissions of hydrocarbons (HC), CO, NOx, CO_2, PM, and air toxics under various conditions, and
- NONROAD Model, for estimating air pollution inventories of nonroad engines, equipment, and vehicles.[8]

Requirements for emission reduction and tracking can be integrated into contracts for cleanup services and products, including those applying to long-term O&M. Examples of contracting language currently used in EPA regions are available in EPA's *Green Response and Remedial Action Contracting and Administrative Toolkit*.[9] The Northeast Diesel Collaborative and some state or local government agencies also have developed model contract language to control diesel emissions from construction projects.[10]

Advanced Diesel Technologies

EPA has set specific limits on the amount of air pollutants that can be released into the environment from various engine types. These standards are structured in a four-tiered progression, with each tier being phased in (based on horsepower rating) over several years. The first federal standards (Tier 1) for new nonroad diesel engines were issued in 1994 for engines over 50 hp and phase-in from 1996 to 2000. In 1998, EPA issued Tier 1 standards for vehicles under 50 hp and more stringent standards (Tier 2 and Tier 3) for all equipment with phase-in from 2000 to 2008. Tier 3 standards only apply to engine sizes of 50 to 750 hp.

In 2004, EPA introduced Tier 4 standards to be phased in from 2008 through 2015. These standards require 90% reductions in emissions of PM and NOx. The reductions can be achieved through integration of advanced diesel technologies for engines and exhaust systems, such as oxidation catalysts and particulate filters.

Clean diesel technologies applied to on-road and nonroad vehicles can significantly reduce diesel pollution created during site investigation and remediation. EPA recommends using three primary strategies to reduce diesel emissions:

- Rebuild engines to meet a cleaner emission standard
- Replace (repower) aged engines or entire vehicles with cleaner burning ones, or
- Retrofit vehicles and equipment with technologies to reduce harmful impacts of diesel exhaust, preferably using technologies verified through EPA's National Clean Diesel Campaign[11] or CARB; many EPA regions now recommend or require machinery and equipment to be retrofit with advanced diesel technologies, as part of regional "green cleanup" policies.[12]

Diesel engines tend to last longer than gasoline engines and are commonly retrofit with a form of advanced exhaust aftertreatment to reduce emissions. One form of advanced technology is the *diesel oxidation catalyst* (DOC), which is a flow-through device that oxidizes CO, gaseous hydrocarbons, and some particulate matter. A DOC can:

- Be installed on almost any new or used engine
- Be used with conventional diesel fuel, biodiesel, and other alternative fuels
- Reduce emission of PM by 20-40%, HC by 40-75%, and CO up to 60%, and
- Cost $1,000-$2,000 for a base metal catalyst.

A *diesel particulate matter filter* (DPF) is a device usually made of ceramic that collects particulate matter in an exhaust stream. High temperatures of the exhaust or an added heat source enable particles collected in the filter to oxidize into less harmful components. Passive DPFs rely on exhaust heat to oxidize trapped particles, while active DPFs employ heating devices powered by electricity or fuel burning. A DPF:

- Can be installed on engines with sufficient exhaust temperatures, such as 250-300°C for passive systems or lower temperatures for active systems
- Typically reduces emission of PM by 95%, hydrocarbons by 90%, and CO by 90%
- Requires use of ultra low-sulfur diesel (ULSD)
- May need periodic cleaning to remove accumulated ash or soot, and
- Typically costs more than $8,000, depending on vehicle types, engine sizes, and installation requirements.

A *partial diesel particulate filter* (pDPF) combines beneficial features of a DOC and DPF. One example of a pDPF frequently used in the cleanup industry is the diesel multi-stage filter (DMF). As a flow-through device, a pDPF experiences less pressure drop than a DPF, while its particle oxidation technology often achieves higher removal efficiency than a DOC. Vehicles retrofit with pDPFs must meet minimum exhaust temperatures for the filters to be effective. A pDPF can:

- Be used on most four-stroke engines in on-road applications if minimum temperature criteria are met
- Reduce emissions by amounts generally ranging between those of a DOC and a DPF
- Need less frequent cleaning or replacement
- Eliminate the need for routine cleaning of ash from exhaust systems, and
- Range in cost from $4,000 to $8,000.

Retrofitting of this emergency response vehicle with a DMF was completed in 2008 as part of EPA Region 10's ongoing clean emission initiative.

DOC, DPF, and pDPF equipment often is combined with closed crankcase ventilation technology, which reduces HC and PM emission from an engine crankcase or oil pan.

Another option for advanced retrofitting is *selective catalytic reduction* (SCR), an emerging NOx emission reduction technology that can be combined with filter and catalyst technologies to reduce emissions of other criteria pollutants. SCR involves injection (into an engine exhaust stream) of urea or other chemicals that will react over a catalyst to form ammonia; the ammonia subsequently reacts with NOx to form N_2 and water. SCR technology requires use of ULSD and periodic refilling of the chemical reservoir. Several applications undergoing verification in the Clean Diesel Emerging Technologies Program suggest that SCR technology could reduce NOx by 65%. SCR systems range in cost from $12,000 to $20,000.

Project managers may be able to take advantage of government funding sources to help cover the costs of retrofit installations and downtime. For example, the California Carl Moyer Memorial Air Quality Standards Attainment Program and the Texas Emissions Reduction Plan offer grants for clean diesel programs.[13]

Emission Reductions and Costs of Diesel Retrofit Technologies[14, 15]

	PM	HC	CO	NOx	Cost Range
Diesel oxidation catalyst (DOC)*	20-40%	40-75%	<60%	-	$1,000-$2,000
Diesel particulate matter filter (DPF)*	95%	90%	90%	-	>$8,000
Partial diesel particulate filter (pDPF)	50%	75%	75%	-	$4,000-$8,000
Selective catalytic reduction (SCR)	-	-	-	65%	$12,000-$20,000

*DOC and DPF technologies can be combined in modular configurations for higher performance, at a cost of $8,000-$10,000

Alternative Fuels and Fuel Additives

Transportation fuel can be used in engines of mobile or stationary equipment and machinery needed for cleanup as well as the on-road or nonroad vehicles used for a project. EPA recommends selecting the most suitable type of fuel(s) for site cleanup based on evaluation of the tradeoffs associated with each fuel's: (1) primary energy source, (2) particular production process and inputs, and (3) availability and transport. In general, substitution of conventional gasoline with diesel can reduce GHG emissions up to 30% due to the higher combustion efficiency of diesel.

Ultra Low-Sulfur Diesel

ULSD is a refined, cleaner diesel fuel with a sulfur content of 15 ppm or less that can be used in any diesel engine. Although only new on-road diesel engines are currently required under federal regulations to use ULSD, after December 1, 2010, ULSD also will be required for nonroad engines (when sourced from large refiners and importers) and in all highway sales of diesel fuel. By 2012, it will be required for marine and locomotive engines.[16]

Similar requirements have become or are becoming effective in some states prior to the federal requirements. All diesel imported to or produced in California since 2006, for example, has been ULSD. States also may require ULSD use in particular programs. The Minnesota Pollution Control Agency uses this approach for leaking underground storage tank projects funded by the American Recovery and Reinvestment Act;[17] all off-road diesel-powered vehicles and equipment (both mobile and stationary) with engine ratings of 50 hp or more must use ULSD and be equipped with retrofit emission control devices verified by EPA or CARB.

Advantages of ULSD include:

- Capability for storage in the same tanks as conventional diesel and use of the same fueling systems
- A 5-9% reduction in PM (without any filters), depending on baseline sulfur levels, and up to a 95% reduction in sulfur dioxide levels
- Compatibility to deploy advanced emission control technologies (DOC, DPF, and SCR) on new and retrofitted diesel engines, resulting in additional emission reductions, and
- Reduced engine wear and tear and potential increase in time between manufacturer-specified oil changes, and generally lower maintenance costs.

Project managers can anticipate that remaining transition from conventional diesel to ULSD may slightly increase fuel costs (+$0.05/gallon) but save more than $0.03/gallon in maintenance costs for heavy equipment and vehicles.

All heavy machinery deployed for removal of petroleum HC-contaminated soil at the Terminal 4 portion of the Portland Harbor Superfund Site in Oregon has used ULSD in advance of federal requirements.

Biofuel

Increased use of *biomass-based renewable fuel* can be another opportunity for reducing air polluting emissions. The quantity of fossil fuel in a transportation fuel can be replaced or reduced by including renewable fuel produced from one or more biomass sources. While conventional biofuel is derived from corn starch, advanced biofuel is produced from other renewable biomass such as:

- Cellulose, hemicellulose, or lignin
- Sugar or non-corn starch
- Waste material such as agricultural crop residue
- Planted trees and tree residue
- Animal waste material and animal byproducts
- Slash and pre-commercial thinning of vegetation
- Algae, or
- Separated food waste such as recycled cooking grease.

Renewable fuel also can be derived from degradation of biomass at landfills or sewage waste treatment facilities. This biogas consists mainly of methane rather than ethanol.

Biodiesel blends contain biodiesel mixed with petroleum-based diesel fuel. Blends of 80% petroleum diesel with 20% biodiesel (B20) can be used in unmodified diesel engines. Procedures for converting to use of blends containing higher percentages of biodiesel typically involve cleaning the tanks that were previously used to store conventional diesel.

Preventive maintenance for equipment rigs using higher blends includes more frequent replacement of the fuel filters. Carrying extra filters "on rig" can significantly avoid work disruption and additional field demobilization and remobilization otherwise needed for filter replacement. Some biodiesel blends also could clog a pDPF; manufacturer confirmation for a particular filter's compatibility with a particular blend is recommended.

Using pure biodiesel (B100) may require engine modifications to avoid maintenance and performance problems. Handling and storage precautions also may be needed for B100 and some biodiesel blends, depending on site-specific climates as well as a fuel's petroleum and biomass constituents.[18] Any biodiesel used for blending should meet ASTM D6751 standards.

Substitution of conventional diesel with B100 can:

- Reduce tail pipe emissions up to 47% percent for PM, 67% for unburned HC, and 48% for CO, but increase NOx emissions up to 10%
- Reduce emission of sulfates up to 100% and HC precursors of ozone by 50%
- Help protect sensitive environments in the event of spills, due to their reduced toxicity (less toxic than table salt) and biodegradable nature (faster than sugar), and
- Improve lubricity of some engines, consequently reducing engine wear and tear.

Depending on the selected blend of biodiesel and site-specific conditions, biodiesel use may be impacted by:

- Slight differences in power, torque, and fuel economy
- Freezing points higher than petroleum diesel, which can cause fuel to gel and related pouring difficulty, and
- Potential need for a stability additive when stored for extended periods.

The price of biodiesel may be slightly higher (an average of +$0.08 per gallon) than regular diesel in some regions, depending on the production processes and availability. The National Biodiesel Board maintains maps of biodiesel retailer locations across the United States.[19]

In addition to considering GHG generation during fuel burning, selection of biofuel should account for a fuel's full lifecycle emission impacts. The impacts include both direct and indirect emissions from factors such as land use changes that result from increased biofuel demand. Project managers can learn more about biofuel production, distribution, and use in analytical reports and other materials compiled by EPA's Renewable Fuel Standard Program, including the Agency's annual renewable fuel standards.[20] The U.S. Department of Energy (DOE) Office of Energy Efficiency & Renewable Energy (EERE) also offers online information about selecting biofuels based on constituent biomass.[21]

Availability and selection of renewable biofuels at a site undergoing cleanup may also be driven by state standards. In early 2010, for example, CARB adopted a Low Carbon Fuel Standard to reduce use of carbon-intensive transportation fuels. Regulations supporting implementation of the standard may include fuel specifications for gasoline with 85% ethanol (E85) and biodiesel/renewable diesel produced or sold within the state.

Cleanup project managers can investigate other renewable biofuel options at sites in close proximity to innovative fuel producers. Sites in or near San Francisco, CA, King County, WA, or Philadelphia, PA, for example, can now purchase commercial-grade biodiesel made from recycled cooking grease or other types of "brown grease." Similarly, algae-produced biodiesel may soon be available from government or commercial test facilities in some U.S. regions. Advantages of algae-based fuel are expected to include:

- Avoidance of competition with agricultural land, products, or fresh water use
- A higher yield per acre (over 100 times more) than biodiesel produced from plants or vegetable oils, and
- Potential use of microalgae strains capable of thriving on seawater or treatment plant wastewater.[22]

Gasoline blends with up to 85% ethanol can be used in all flexible fuel vehicles (flex-fuel vehicles, or FFVs). FFVs typically experience no performance loss but operate 20-30% fewer miles per gallon (mpg) when fueled with E85. Information about modifying vehicles to operate on alcohol blends and other alternative fuels is available online from EPA's Office of Transportation and Air Quality (OTAQ).[23]

Profile: Marine Corps Base Camp Pendleton
San Diego County, CA

- *Used clean diesel technology to excavate 120,000 yd^3 of soil contaminated by metals, dioxins/furans, and pesticides*
- *Selected biodiesel blends (primarily B20) to power all field equipment used for excavation*
- *Retrofitted two equipment pieces with DPFs, which reduced particulates by more than 85%*
- *Selected six equipment pieces classified as Tier 3 technology, which reduced PM10 emissions by 63% when compared to Tier 1 technology*
- *Transported 30,380 tons of excavated soil by way of train rather than trucks, an equivalency of removing 1,215 trucks (of 25-ton capacity) off southern California highways*
- *Potentially integrating cleanup activities into Camp Pendleton's shift to clean fuel technology, which includes use of 320 electric vehicles routinely charged at an onsite 8-station charging facility powered by solar resources.*

Fuel Additives

Project planning can also take advantage of many fuel additives available from specialty fuel retailers. Additives can enhance fuel performance and often result in improved fuel economy and lower air emissions. Although many gasoline, diesel, biodiesel, and detergent additives are available, as registered with EPA,[24] certain categories can achieve significant reductions in targeted compound emissions.

Emulsified diesel is a blended mixture of diesel fuel, water, and emulsifying and stabilizing additives that can reduce emissions of PM up to 60% and NOx up to 20%. One example is PuriNOx, a water emulsion alternative fuel verified by EPA in reducing emission of PM by 16-58% and NOx by 9-20% in heavy-duty 2- and 4-cycle engines when used at temperatures higher than 20°F.[11]

Other EPA-verified fuel additives to consider include cetane enhancers, which can reduce NOx emission up to 5%, and platinum-based fuel additives undergoing additional EPA research. Fuel-borne catalysts verified under EPA's Environmental Technologies Verification Program provide another option.[25] More information on verified alternative fuels and additives is available from EPA[26] and CARB.[27]

It's Only One SUV! *A 15-mpg passenger vehicle used during site preparation, remedy construction, and five years of remedy operation, traveling a weekly average of 100 miles for onsite and local activities, would consume more than 1,700 gallons of gasoline . . . emitting the equivalent of 15.1 metric tons of CO^2.*

Greenhouse Gas Equivalencies Calculator:
http://www.epa.gov/cleanenergy/energy-resources/calculator.html

Fuel Efficient and Alternative Vehicles

From 1990 through 2006, transportation accounted for 47% of the net increase in total U.S. emissions of GHG. In 2006 alone, mobile sources caused an estimated 28% of the U.S. GHG emission. Mobile sources used during site cleanup typically include:

- Light-duty vehicles, which constitute a category of vehicles with a gross vehicle weight rating (GVWR) below 8,500 pounds, such as passenger cars, sport-utility vehicles (SUVs), light-duty trucks, and medium-duty passenger vehicles
- Heavy-duty commercial vehicles such as cargo vans or light trucks rated above 8,500 pounds GVWR; a truck of this weight class is commonly used during site cleanup as a base platform for equipment such as hollow-stem auger drill rigs, and
- Nonroad mobile sources powered by internal combustion engines but not used for transportation (and subject to other CAA regulations), including construction machinery such as bulldozers, excavators, and forklifts.[28]

Each gallon of gasoline consumed during site cleanup results in a 20-pound emission of CO_2.

Replacement of aged vehicles with newer ones operated by more fuel-efficient engines or relying on alternative fuel can significantly reduce fossil fuel consumption and associated air emissions. Deploying vehicles with higher fuel efficiency for both onsite and offsite activities should also lead to lower fuel costs for site cleanup. Additional savings can be gained by non-government fleet owners when purchasing alternative vehicles qualified for federal or state tax credits.

Alternative vehicles include those using electric, hybrid gasoline/electric, or compressed natural gas fuel systems. When purchasing alternative vehicles, project managers and fleet owners can use life cycle analysis to evaluate the options and optimize decisions. Environmental benefits of converting to electric vehicles (EVs), for example, can be greatly enhanced if the needed electricity is produced from onsite or "upstream" renewable resources.

Decisions on whether, and when, to replace aged vehicles with new models may be affected by upcoming changes in the automotive market. For example, standards proposed by EPA and DOT's National Highway Safety Administration in September 2009, would require all 2012-2016 model light-duty vehicles (which are responsible for nearly 60% of all transportation-related GHG) to meet specific criteria for GHG emissions and fleet average gas mileage.[29]

Electric Vehicles

Increased substitution of conventional vehicles with EVs is one option for integrating alternative vehicles during site cleanups. An EV employs an electric motor powered by an onboard, rechargeable storage battery that is periodically recharged by an external source of electricity. Vehicles powered by electricity offer the advantages of:

- Cleaner operation than conventionally powered vehicles, due to the absence of polluting byproducts generated by internal combustion engines
- A "tank-to-wheels" efficiency about three times higher than the typical 20% conversion efficiency of an internal combustion engine vehicle (due to engine friction, air pumping, and wasted heat)
- Potential incentives offered by government agencies, which can offset higher capital costs
- Quieter operation, and
- Fewer moving parts, with no oil changes.

Project managers can consider use of low-speed neighborhood electric vehicles (NEVs) for local trips or onsite activities such as maintaining field equipment or collecting field data. Full recharge of a NEV can be completed in 2-3 hours when using a 220-volt outlet or in 6-8 hours with a standard 110-volt outlet. Larger all-electric vehicles expected to enter the U.S. market in 2010-2012 are predicted to travel 100-200 miles before needing a recharge.

Hybrid Vehicles

Another option is to substitute conventional vehicles with hybrid vehicles. A hybrid vehicle uses two or more distinct sources of power. The most common is a hybrid electric vehicle that employs an internal combustion engine and one or more electric motors. Hybrid vehicles offer the advantages of:

- Regenerative braking that activates drivetrain resistance, causing the wheels to slow down; in return, energy from the wheels turns the motor (which functions as a generator) to convert energy normally wasted during coasting and braking into electricity, which is stored in a battery until needed by the electric motor
- Electric motor drive/assist that provides additional power for engine acceleration, allowing a smaller, more efficient engine to be used, and
- Automatic start/shutoff systems programmed to cut an engine when a vehicle comes to a stop and restart it when the accelerator is pressed; this feature prevents wasted energy from idling.

Plug-in hybrid electric vehicles (PHEVs) expected to become available by 2012 will rely on battery-supplied electricity to travel longer distances (10-40 miles) before activation of the gas engine. Full recharging of a PHEV battery will take approximately 6 hours when using a 220-volt circuit.

Another innovative technology is used in hydraulic hybrid vehicle (HHVs), which integrate new designs for regenerative braking, optimum engine control, and engine shut-off during "stop and go" operation. HHV demonstration has shown that HHV technology can improve fuel efficiency of light-duty trucks and SUVs up to 70% and reduce their CO_2 emissions by 40%.[30]

EPA ***Clean Air Excellence Awards*** *merited in 2009 for clean air technology included the:*

- *Caterpillar D7E track-type tractor, which uses an electric drive system to decrease fuel consumption by 10-30% and increase dozing efficiency by 25%, while using fewer mechanical parts and fluids*
- *Kenworth natural gas powered vehicle, which uses a small injection of diesel to more effectively ignite natural gas serving as the primary fuel source (reducing NOx emissions by 27%, PM by 40%, and CO_2 by 24% when compared to diesel fueling)*

Information on other award-winning technologies applicable to vehicles used for cleanup is available at: http://www.epa.gov/air/caaac/recipients.html.

Compressed Natural Gas Vehicles

Compressed natural gas (CNG) is one alternative fuel targeted under the Energy Policy Act. Natural gas vehicles (NGVs) are fueled exclusively with CNG or are capable of natural gas and gasoline fueling (bi-fueling). Many light-duty vehicles can be retrofit to use CNG engines, and natural gas engines and fueling systems are available for heavy-duty vehicles such as waste hauling trucks. Advantages of NGVs include:

- Combustion resulting in lower amounts of harmful emissions such as GHG, NOx, PM, and other pollutants, when compared to gasoline or diesel
- Ready availability of CNG in the fuel distribution market (although retail fueling stations are sparse), and
- Demonstrated success in many industrial or government fleets.

Fuel economy of an NGV is comparable to vehicles powered by conventional gasoline.

EERE offers more information on performance, energy efficient technologies, and comparisons of alternative vehicles.[31] In partnership with EPA, EERE also offers information about fuel economies of the various alternative vehicles.[32]

EERE's ***Alternative Fueling Station Locator*** *provides online mapping of refueling stations for biodiesel, compressed natural gas, electric, ethanol, and hydrogen fuel.*[33]

Key Resources

Federal or state programs offer tools and information resources to help implement vehicle- and fuel-related BMPs for green cleanups.

- EPA's *National Clean Diesel Campaign* provides information and incentive funding for cost-effective, verified technology to reduce harmful diesel emissions.[34]
- EPA's *SmartWay®* collaborates with the freight industry to reduce air emissions and improve fuel efficiency by selecting certified vehicles, tractors, and trailers.[35]
- The *EPA Environmental Technology Verification* program provides information on verified technologies for products such as mobile source devices, emulsified fuels, and baghouse filtration systems.[36]
- The *California Air Resource Board* offers information on diesel or alternative fuels and verifies diesel emission control products.[37]
- Regional *Clean Diesel Collaboratives*, which are public-private partnerships, aimed at improving air quality through projects using innovations in diesel engines, alternative fuels, and renewable energy technologies. Members of the (now seven) collaboratives work together to leverage funding, share technology, and professional expertise.[38]

A Sampling of Success Measures for Clean Fuel & Emissions

- *Lower rates of fuel consumption as a result of using more efficient vehicles, machinery, and equipment*
- *Increased substitution of fossil fuel with fuel produced from renewable resources*
- *Lower emission of GHG, PM, and other air toxics and associated global warming*
- *Reduced air emissions and fugitive dust impacting local communities*
- *Lower cleanup costs due to reduced fuel consumption and equipment repairs*
- *Beneficial use of industrial or agricultural waste as fuel feedstock*
- *Increased energy independence of sites undergoing cleanup*
- *Reduced loads on fuel production and transport infrastructures*

Clean Fuel & Emissions: Recommended Checklist
Operations and Maintenance
✓ Implement an idle reduction plan ✓ Assure proper tune-ups of vehicles and equipment and maintenance of fuel storage tanks ✓ Establish routines for daily activities such as using biodegradable lubricants, closely managing petroleum-product waste materials, driving efficiently, and inflating tires properly ✓ Track fuel consumption and associated emission of GHG and air toxics and set reduction goals
Advanced Diesel Technologies
✓ Rebuild engines to meet cleaner emission standards ✓ Repower vehicles with new engines or replace aged vehicles with new vehicles ✓ Retrofit existing equipment with aftertreatment devices
Alternative Fuels and Fuel Additives
✓ Retrofit all existing nonroad equipment to use ULSD ✓ Use biodiesel produced from waste or agricultural products with reduced lifecyle GHG emissions ✓ Select fuel with additives that can further reduce air emissions
Alternative Vehicles
✓ Replace conventional vehicles with electric fuel, hybrid, or compressed natural gas vehicles

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EPA is publishing this fact sheet as a means of disseminating information regarding the BMPs of green remediation; mention of specific products or vendors does not constitute EPA endorsement.

Visit *Green Remediation Focus* online:
http://cluin.org/greenremediation

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Office of Solid Waste and
Emergency Response (5102G)

EPA 542-F-11-006
April 2011

Green Remediation Best Management Practices:
Integrating Renewable Energy into Site Cleanup

Office of Superfund Remediation and Technology Innovation | Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outline the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) identified in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis, while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.[2]

Overview

Use of renewable energy resources provides a significant opportunity to reduce the environmental footprint of activities conducted during investigation, remediation, and monitoring of hazardous waste sites. Substitution of energy from fossil fuel resources with energy from renewable resources is a primary approach for addressing energy as one of the five core elements of green remediation strategies. In turn, lower consumption of fossil fuel will reduce emission of greenhouse gases (GHG) as well as particulate matter and other air pollutants.

EPA estimates that operation of 12 common cleanup technologies at Superfund sites could consume an average of 631,000 MWh annually between 2008 and 2023,[3] a quantity equivalent to the electricity consumption in about 55,000 homes over one year.[4]

Technology	Average Annual Electricity Consumption (MWh)	Average Annual Cost ($)*
Pump and treat	490,000	52,381,000
Thermal desorption	93,000	9,941,700
Multi-phase extraction	18,700	1,999,030
In situ thermal treatment	13,000	1,389,700
Air sparging	10,000	1,069,000
Soil vapor extraction	6,700	716,230
Ex situ stabilization	22	2,352
Other**	6	641
Total	631,428 MWh	$67,499,653

* Using the August 2010 national average of $106.90/MWh for commercial use

**Including ex situ bioremediation of soil, in situ bioremediation (source), in situ chemical oxidation (source), in situ bioremediation of groundwater, and in situ chemical oxidation of groundwater

Renewable sources of energy for production of electricity or direct power needed for site cleanup can include:

- *Solar* resources captured by photovoltaic (PV), solar thermal, and concentrating solar power systems
- *Wind* resources gathered through windmills to generate mechanical power or turbines of various sizes to generate electricity
- *Geothermal* resources, primarily through geoexchange systems such as geothermal heat pumps or by accessing subsurface reservoirs of hot water
- *Hydrokinetic* and *marine* resources, through the hydropower of rivers and streams or the tidal and thermal influences of oceans, and
- *Biomass* such as untreated woody waste, agricultural waste, animal waste, energy crops, landfill gas and wastewater methane, anaerobic digestion, and algae.

Methane captured from decomposing organic materials in landfills or wastewater treatment can also be used for direct heating rather than for electricity generation. Aspects of using this (ultimately finite) source of energy will be described in EPA's upcoming fact sheet on best management practices for addressing landfills at contaminated sites.

Evaluating the potential for integrating renewable energy at a hazardous waste site to achieve a "greener cleanup" typically involves:

- *Maximizing energy efficiency and monitoring energy demand* of remediation system(s), auxiliary equipment, buildings or sheds, and the supporting infrastructures for a new or existing project [page 2]
- Exploring potential applications for *onsite production of energy* from renewable resources [page 2]
- Conducting a preliminary renewable energy assessment to obtain site-specific information [page 6]
- Conducting a detailed *economic and technical feasibility study* for large or utility-scale renewable energy projects [page 6], and
- Considering *purchases of clean energy* from offsite resources through various mechanisms such as renewable energy certificates [page 7].

Lighten the Energy Load First

Use your energy dollar wisely by beginning with an energy audit and consistently using BMPs for energy conservation and efficiency.

Maximizing Energy Efficiency and Monitoring Energy Demand

EPA's *Principles for Greener Cleanups* establish a goal to reduce the environmental footprint of cleanup activities to the maximum extent possible. To achieve this goal, a wide variety of strategies could be employed to *minimize total energy use and maximize use of renewable energy*, as one element of a greener cleanup. General BMPs for energy conservation and efficiency include:

- Retaining in-house experts or hiring a professional auditor to conduct an energy audit of existing systems for treating contaminated soil/sediment, ground/surface water, and air, as well as supporting buildings. A walk-through with an auditor using thermographic equipment, for example, can quickly reveal air loss from heating or cooling equipment. No/low cost energy audits may be available from a local utility provider, and many state or local agencies can assist in finding qualified auditors.

> *The **Association of Energy Engineers** (AEE) offers a directory of professionals certified by AEE in specialized energy areas.*[5]

- Following equipment vendor recommendations for routine maintenance, conducting periodic inspections, and quickly repairing or upgrading industrial equipment such as fans, pumps, air compressors, dryers, and steam units, when needed.
- Periodically re-evaluating existing treatment systems to identify opportunities for remedial system optimization, which could involve changes such as equipment downsizing or shutoff. BMPs for optimizing efficiency of common cleanup technologies such as pump-and-treat (P&T), soil vapor extraction (SVE) systems, and bioremediation are described in other fact sheets of EPA's publication series on green remediation.[6a,b,c]
- Using Federal Energy Management Program (FEMP) energy conservation/efficiency tools such as the FEMP checklist of measures for office settings (including temporary modular or mobile facilities) and suggested processes for procuring industrial equipment.[7,8] Other opportunities for technical and planning assistance to add renewable energy sources at federal facilities may be available through energy savings performance contracts (ESPCs) with the U.S. Department of Energy (DOE).[9]

Increased awareness of a cleanup project's energy consumption often leads to increased use of energy efficiency/*conservation measures.* Project managers are encouraged to routinely track energy use through utility-provided meter readings and tools such as:

- Online calculators or software available from government or non-profit organizations at no cost, such as the NOx and Energy Assessment Tool (NxEAT); EPA offers an online compendium of such tools[10]
- Commercial software products
- A plug-based meter to measure power use of small devices consuming "vampire loads" (when the device is turned off) and connection of these devices to a switchable power strip or "smart" surge protector, and
- An inexpensive whole-building, whole-system, or sub-metering device installed at the electricity meter or service panel to record and display consumption information; this device also can be used to monitor onsite energy production. At the Pemaco Superfund Site in Maywood, CA, for example, an integrated DC/AC system supporting groundwater P&T operations and a roof-top PV array provides real-time data on daily and lifetime energy production, PV array voltage and current, and utility voltage and frequency.

Additional reductions in energy costs can be gained by modifying a treatment system to operate at a heavier load during nonpeak, lower-cost hours assigned by the local utility. This type of system optimization also will reduce loads on the utility grid during peak hours. Other information that can help an organization conduct a self audit of industrial processes is available from the EnergyStar® Program.[11]

> *How Clean Is the Electricity at Your Site?*
>
> *The Green Power Partnership offers the **PowerProfiler** tool to determine air emissions associated with your electricity supplier's particular fuel mix.*[12]

When designing a new remedial system or evaluating options to increase efficiency of an existing system, project managers can also consider offsite energy usage such as the electricity needed to manufacture remedial materials. Doing so may help avoid simply shifting the energy demand from an onsite to an offsite source or substituting one form of petroleum-based energy with another.

Onsite Production of Renewable Energy

EPA encourages project managers to explore methods for producing energy from onsite resources during all stages of site investigation and remediation. Related BMPs include:

- Using micro-scale forms of renewable energy for small equipment and portable devices
- Implementing small-scale renewable energy systems (typically rated below 10 kW) that provide direct power for selected components of a treatment system, supplement energy drawn from the grid, or meet the power demand of "polishing" technologies
- Designing medium- and large-scale systems that meet more or all of the onsite energy demand or much of the demand over long-duration cleanups; system scaling should account for potential reduction in the demand as cleanup progresses, as well as the possibility to re-purpose the system over time

- Considering utility-scale facilities (rated above 1 MW) that meet onsite demand and/or feed to the grid for offsite use, through partnerships with utility companies and/or independent developers or through full ownership
- Using hybrid systems that produce power from multiple renewable resources
- Designing phase-in approaches that accommodate limited budgets for capital expenses or meet energy demands of activities on uncontaminated portions of a site over time
- Striving for 100% onsite renewable energy sources at remote locations to avoid increased utility loads and costs for grid connection, and
- Capitalizing on financial incentives such as federal or state tax credits and rebates; in some incentive structures, credits may be transferred from ineligible purchasers to eligible project partners.

Field Applications

Use of these strategies and BMPs in various scales and combinations is illustrated at several ongoing or completed cleanups. At the GM Powertrain site in Bedford, IN, for example, *micro-scale PV equipment* was used to power weather stations and stream gauge monitors that guided removal actions along a five-mile stretch of contaminated soil. Information collected from both the weather stations and stream gauges was transmitted to an onsite trailer where it was recorded on a computer that operated data logging software. Use of this relatively inexpensive system avoided the need for frequent replacement of batteries or infeasible access to grid electricity at remote offsite locations. Solar-powered equipment such as this also could be used during site investigation, remediation feasibility studies, and monitoring of long-term remedial work.

The Lake City Army Ammunition Plant near Kansas City, MO, offers an example of *integrated units* comprising commonly used remedial equipment along with a renewable energy source. Five solar-powered skimmer pumps were used to recover approximately 200 gallons of non-aqueous phase liquid from depths reaching 180 feet. Each unit, which cost about $6,000, included a 65-watt PV panel and a vacuum/canister pump assembly. The recovery system fully operated off-grid and could be transferred from one well to another, as needed.

Small-scale renewable energy systems can be designed with or without intertie to the utility grid. Off-grid SVE at the former Ferdula Landfill in Frankfurt, NY, relies on a wind-driven vacuum process rather than electrically powered air blowers. Over the initial five years of operation, concentrations of target volatile organic compounds (VOCs) decreased by more than 90%. Based on the amount of energy provided by the system's single windmill, the $14,000 capital/installation cost of this wind system was recovered within the first year of operation due to avoided electricity purchasing. Operation and maintenance (O&M) cost for the wind-driven extraction system is below $500 each year. In contrast, the site owner estimates that installation of a conventional, 25-hp blower-driven SVE system achieving a comparable rate of VOC removal would have cost nearly $500,000 and involved an annual O&M cost of $75,000.

Small-scale systems can also introduce renewable energy at sites with limited space or in densely populated areas. At the Frontier Fertilizer Superfund Site in Davis, CA, a $35,000 5.7-kW PV array was installed in 2007 on the roof of a building used for ex situ groundwater treatment. Successful integration of solar energy and availability of American Recovery and Reinvestment Act (ARRA) funding led to 2010 expansion with a significantly larger (68-kW), ground-mounted PV system on 0.5 acres adjacent to the building. The PV system now meets 100% of the remediation system's annual energy demand, which encompasses operation of 16 wells that extract groundwater for treatment in granular activated carbon vessels.

Costs for the new PV system totaled approximately $350,000, which was fully covered by ARRA funding. EPA Region 9 also will receive approximately $100,000 in state renewable-energy rebates to be incrementally dispersed on a monthly basis over five years; these funds will be applied toward implementing the site's 25- to 30-year cleanup plan. Based on a current annual savings of $20,000 (due to avoided electricity purchases) and utility forecasts, the federal government will recover capital and installation costs for the new system in approximately 14 years. Substitution of fossil-fuel generated electricity with the onsite renewable energy is anticipated to reduce indirect emission of carbon dioxide (equivalent) by approximately 119,000 pounds each year over the PV system's anticipated 20-year lifespan.

Some renewable energy systems are designed to *operate on- or off-grid* to accommodate changing site conditions or project constraints. Decisions regarding grid-intertie also may be affected by whether production of excess energy can result in financial benefits such as utility net metering. At the former Nebraska Ordnance Plant in Mead, NE, for example, a 10-kW wind turbine powers groundwater circulation wells used for air stripping and ultraviolet (UV) treatment. The system reduces consumption of utility electricity by 26% during grid intertie mode but can also operate off-grid when needed. Over 15 years, the electricity savings could exceed $40,000. Estimates at the time of wind turbine installation (2003) suggested that a similarly sized system operating fully off-grid would cost approximately $45,000.

Corrective action at the former St. Croix Alumina Plant in St. Croix, VI, relies on a *hybrid system* that employs both solar and wind resources to recover hydrocarbons from groundwater. Since 2002, the system has expanded on a *modular basis* to include:

- Four wind-driven turbine compressors for powering seven pneumatic pumps; four of the pumps are set at the oil/water interface for skimming hydrocarbons, and three are set below the water table for total fluid recovery
- Four wind-driven electric generators (WEGs) to power four submersible pumps and the fluid-gathering system; at an average wind speed of 12 mph, each WEG provides 6.8 kWh/day
- A 495-watt PV system to provide additional electricity for the submersible pumps and fluid-gathering system, and
- Control panels that can draw electricity from either the WEGs or PV panels, or both, as needed.

Use of this direct drive electricity system avoids the need for storage batteries, consequently lowering the project's capital and maintenance costs and avoiding battery disposal. Capital costs (excluding wells and pumps) totaled approximately $50,000, or about 50% of the expected cost for grid connection. More savings were gained through federal tax credits received by the site owner. Each day, the system recovers approximately 113 gallons of free product and 25,000 gallons of groundwater.

At the Summitville Mine Superfund Site in Colorado, a new 36-kW *micro hydroelectric plant* will begin operating in 2011 after three years of construction. The plant will generate electricity for an onsite water treatment facility used for long-term treatment of mining-impacted water of the Alamosa River network. Electricity production will rely on energy of water diverted from Whiteman Fork Creek to the plant, over a 65-foot drop. Construction included installing an inlet structure and 16-inch penstock that delivers diverted water to the plant's turbine at an average rate of 10 cubic feet per second, although flow rates will vary through the seasons.

The water treatment facility uses approximately 1 million kWh of electricity each year to operate at a rate of 1,600 gallons per minute. (Due to snow buildup on nearby and onsite roads, the site typically shuts down for five months each year.) EPA Region 8 expects the new power plant to generate approximately 145,000 kWh/year (equivalent to powering about 20 homes) and avoid emission of 120 metric tons of carbon dioxide associated with regional electricity production. This production rate will meet 15-20% of the existing treatment facility's energy demand and is expected to reduce cleanup costs by approximately $15,000 each year due to avoided electricity purchases. Near-term completion of a more efficient water treatment facility is expected to additionally reduce the amount of needed grid electricity.

Integration of renewable energy for site cleanup can also involve *creative partnerships*. Groundwater remediation at the Aerojet-General Corporation Superfund site in Rancho Cordova, CA, for example, involves a public/private partnership among the property owner, the Sacramento Municipal Utility District (SMUD), and an energy developer. Groundwater extraction and ex situ treatment is powered by an onsite 6-MW solar farm. The 40-acre farm meets about 30% of the remediation system's total power demand, including electricity for air-stripping units, UV reactors, and ion exchange vessels treating over 20 million gallons of groundwater each day. Each year, substitution of grid electricity with power generated by the solar farm avoids an estimated 6,000 tons of carbon dioxide, 5 tons of nitrogen oxide, and 4 tons of sulfur dioxide.

Capital costs totaling approximately $20 million are offset by about $13 million in incentives to be provided by SMUD over a 10-year period. Over the project's 25-year life, use of solar energy is anticipated to save more than $10 million in electricity costs. Reuse plans for other parts of the site include residential and industrial properties that could benefit from future expansion of the solar farm.

Lessons Learned

Based on information shared by project managers experienced in installation and use of onsite renewable energy systems, EPA has identified BMPs associated with *logistics*, such as:

- Carefully planning transport of large and heavy components such as wind turbine blades and nacelles; this can involve state/local permits, schedules for police escorts and suitable weather, navigation of structures such as bridges, and travel on unpaved roads
- Incorporating additional security measures to prevent damage or theft of system components, and
- Instituting clear maintenance plans for solar or wind equipment and auxiliary components such as data loggers (particularly components exposed to weather), forecasting sufficient budgets for the maintenance, and assuring the plan can continue during long-term O&M conducted by state or other organizations; large systems also need advanced plans for future decommissioning.

Other BMPs based on lessons learned relate to *improved remedial system designs and construction* that can better integrate renewable energy:

- Siting a new treatment facility/system to meet renewable energy system needs, even when onsite renewable energy is not used immediately; for example, south-facing orientation of a treatment building would maximize benefits of a future PV system
- Designing treatment systems that operate intermittently (while still meeting cleanup goals) to match renewable energy availability, consequently avoiding the need for storage batteries that typically result in efficiency loss
- Adequately freeze-proofing cleanup components such as groundwater circulation wells during construction, to avoid energy loss in pumps and auxiliary equipment used on a year-round basis, and
- Designing for maximum use of renewable energy to treat air with low concentrations of contaminants; examples include solar-powered flares for low volumes of passive landfill gas, small solar-powered fans for mitigating soil vapor intrusion into buildings, and vent stack-mounted wind turbines to reduce pressure within air stacks and draw soil vapor from beneath building slabs.

EPA also recognizes *general practices in the renewable energy industry*:

- Coordinating early with the local utility when designing a renewable energy system to be tied to the grid, to assure equipment such as circuit breakers and all installation methods meet the utility's standards and maximizes protection of utility lines as well as onsite power lines
- Scheduling sufficient planning time that accounts for operational permitting, availability of preferred installers, and potential backlogs in equipment manufacturing
- Taking advantage of economies of scale; for example, labor costs for installing each unit of a large "surplus energy" system may be lower than for a smaller system
- Considering use of several microinverters rather than a large central inverter for AC/DC conversion, to prevent full shutdown if an individual component fails, and
- Including solar thermal technology as an option, which can be used to heat water needed for industrial systems at a cost typically lower than PV systems.

Results from the Agency's remedial optimization studies indicate that increased use of *geothermal energy* can provide additional project efficiencies. Potential methods for tapping this renewable source of energy include:

- Using geothermal heat pump systems to condition interior air of buildings; these systems rely on a relatively simple ground heat exchanger and heat pump to capture the natural heat (or cold air) in shallow ground, which typically remains at 50-60°F
- Integrating a heat exchange system to capture thermal mass in pumped groundwater prior to treatment (and reuse excess heat generated by P&T processes)
- Using combined heat and power (CHP or "cogeneration") to drive a closed-loop P&T system
- Installing subsurface piping to access shallow aquifers that also can provide a heat exchange system
- Modifying equipment such as standard diesel generators to recover, store, and reuse energy otherwise lost as "waste heat," and
- Installing heat collectors within ground surface asphalt, from where a heat pump can recover and deliver heat to aboveground areas or to contaminated subsurface areas for enhanced biological degradation.

Managers of cleanup projects in the vicinity of suitable feedstock producers can also use *biomass resources* to generate energy. One simple application is the use of electricity generators that are converted to operate on material such as wood pellets instead of diesel fuel. In contrast, DOE's Savannah River Site provides an example of large-scale use of biomass resources. Two new biomass-

fueled boilers have replaced fuel oil-fired boilers that support K Area and L Area cleanups. The new boilers operate on 100% biomass consisting primarily of forest logging residue and local wood waste.

More information about renewable energy technologies for remedial actions is available in EPA's *Smart Energy Resources Guide*.[13]

*EPA's **RE-Powering America's Land** initiative identifies renewable energy development potential on current and formerly contaminated land and mine sites. Online information includes state and national maps displaying these sites and details about related incentives.*[14]

Renewable Energy Assessments

A renewable energy assessment provides general information about how renewable resources could be used to meet the energy needs of a cleanup. A qualified third-party site assessor can fully analyze the site, its infrastructure, and past records on energy use. Although many assessors specialize in particular technologies such as PV systems, some are qualified to assess multiple resources. At sites where certain technologies are targeted, vendors or installers of these systems may offer site assessments for fees to be credited against future purchasing or installation costs. Yet others may provide no-cost assessment as part of a bidding process, particularly for large-scale projects.

> *The **Midwest Renewable Energy Association** offers an online locator for finding certified assessors.*[15]

Project decision-makers should assure that a renewable energy assessment includes:

- General analysis of the energy demand and additional recommendations for energy efficiency
- Preliminary evaluation of the site's renewable energy resources, which may include multiple sources
- Estimated output of the renewable energy system(s)
- Recommendations on specific locations at which to place the system, and associated site conditions
- An estimated cost range for the system, with a list of specifications or conditions that could influence costs, and
- A list of pertinent federal, state, and public utility incentives applying to the site.

> *Organizations such as the **American Wind Energy Association** and **Solar Energy Industries Association** and local chapters offer hands-on workshops and webinars.*[16,17]

Alternatively, in-house staff who are properly trained in planning and managing renewable energy systems (particularly small-scale applications) can be an asset to organizations that manage or oversee cleanup at multiple sites. Ready access to such experts may reduce the costs and additional time associated with procurement of outside consultants, improve treatment-system optimization efforts, and enhance plans for long-term remedial operations. In-house experts could also help organizations gain efficiencies concerning administrative and technical continuity among sites, including the potential to reuse a renewable energy system no longer needed for its original remedial purpose. During renewable energy resource assessment, specialized activities could include:

- Researching existing data available from DOE's National Renewable Energy Laboratory (NREL), which offers maps, geographical information system (GIS) data, and meteorological ("met") data from U.S. measurement stations[18]
- Investigating access to data that may be available from other organizations who routinely gather information at nearby met towers
- If insufficient data are available, conducting a detailed wind energy evaluation through installation of one or more met towers and interpretation of data collected over 12 months
- Using equipment such as radiometers and sun trackers for precise measurement of solar radiation and using online tools such as PV Watts[19] or RETScreen®[20] to calculate energy production and cost savings
- Integrating geothermal applications in treatment system and building designs
- Designing suitable specifications to include in materials for procuring equipment, installers, or maintenance providers of renewable energy systems, and
- Using software models such as NREL's CREST or SAM to assess renewable energy cost incentives.[21]

More information on assessing solar, wind, water, geothermal, and biomass resources is available from the DOE Office of Energy Efficiency and Renewable Energy (EERE).[22]

> *The **Database of State Incentives for Renewables and Efficiency** (DSIRE) is frequently updated with new information on state, local, utility, and federal incentives available in each state.*[23]

Economic and Technical Feasibility Studies

A technical and economic feasibility study provides detailed, site-specific information on the potential to install a large or utility-scale renewable energy system. Based on electric load and cost data for existing or in-design treatment systems, the study will evaluate options and help assure long-term cost savings. The study should include:

- Detailed description of the anticipated energy resource
- Estimates of annual energy production
- Annual O&M costs, and
- Life-cycle cost analysis of initial expenses, energy savings, financial incentives, and simple payback.

> *NREL's **Feasibility Study of Economics and Performance of Solar Photovoltaics at the Stringfellow Superfund Site** in Riverside, CA, illustrates the detail involved in renewable energy studies.*[24]

The study also should compare costs and key technical considerations for alternatives such as:

- Continuing to purchase electricity from the existing utility
- Integrating the renewable energy system into the existing electrical distribution system with an appropriation or other available funds
- Integrating the renewable energy system into the existing electrical distribution system under an ESPC or utility energy savings contract, and

- Leasing a portion of the site to a third-party developer for renewable energy production while purchasing renewable electricity through a power purchase agreement (PPA). The Fort Carson military base in Colorado, for example, leases land to the local utility, which in turn supplies electricity to the base at a discount. Capital costs for the site's 2-MW solar farm, which is situated on a new evapotranspiration landfill cover, were paid by an independent developer. In addition to reducing the base's operational costs, installation of the solar farm provided the opportunity to productively reuse areas occupied by the properly capped landfill. Evaluation of the solar energy potential also led to installation of several small, off-grid PV systems for other onsite needs, such as pumping fresh water to drinking tanks for wildlife.

At the Massachusetts Military Reservation (MMR), multiple assessments of renewable energy resources have led to a comprehensive approach for installing renewable energy systems as part of the U.S. Air Force Center for Engineering and the Environment (AFCEE) optimization program. MMR's remediation program involves nine P&T systems (operating at a maximum flow rate of about 17-18 million gallons per day) and a widespread monitoring well network. Annual electricity costs for the treatment systems had reached approximately $2.2 million by 2008.[25] Under the Massachusetts net metering program, AFCEE anticipates a seven- to eight-year return on a $4.6 million, 1.5-MW wind turbine that began operating onsite in December 2009.

MMR completed a follow-on renewable energy study and environmental assessment and subsequently awarded a contract to construct two more 1.5-MW wind turbines. The turbines will collectively offset 100% of the treatment systems' energy use. In addition, NREL is conducting a feasibility study (under EPA's RE-Powering America's Land initiative) on viability of a solar farm at the MMR landfill.

*EPA's **Greener Cleanups Contracting and Administrative Toolkit** provides samples of specifications in service contracts executed by EPA and other agencies to help institute use of renewable energy during site cleanup. The Toolkit also contains related language incorporated in records of decision, consent decrees, and other administrative documents.[26]*

Purchasing Clean Energy from Offsite Resources

EPA encourages voluntary purchases of clean energy for use at sites where onsite production of renewable energy is technically or economically infeasible or cannot meet the full energy demand of cleanup. Recent NREL studies estimate that the total retail sales of renewable energy in voluntary markets exceeded 30 million MWh in 2009, a 17% increase from the previous year.

Cleanup project managers can work with their utility procurement affiliates to purchase clean energy through a number of options involving electricity generated from offsite renewable resources ("green power") or *renewable energy certificates* (RECs). Also known as "green tags," RECS represent the clean energy attributes of renewable energy production. Sales of RECs accounted for approximately 62% of the clean energy market in 2009.

In many cases, green power equal to all or a share of a project's energy needs can be purchased directly from a utility through a ***green pricing program***. A list of utilities offering green power options is available from EERE.[27] In states with restructured electricity markets, renewable energy also is available from *competitive providers* of electricity or RECs. Additional information about utility green pricing, green power marketing, and RECs is available from DOE's Green Power Network.[28]

When considering REC purchases, the potential of a purchase to encourage development of new renewable energy projects should be evaluated. To additionally maximize a REC purchase's impact on growth of the renewable energy sector, managers of long-term cleanup projects can consider purchasing RECs as part of a five- to ten-year year contract from a renewable energy project that has not yet been built.

Many renewable energy products in the retail market are certified by independent parties as a means of increasing the credibility of renewable energy and environmental benefit claims. The Green-e Energy program administered by the non-profit Center for Resource Solutions, for example, provides clear criteria for renewable energy products and enables sellers of renewable energy products to voluntarily conform to the program's standard.[29]

*More insight on clean energy is available in the **Guide to Purchasing Green Power: Renewable Electricity, Renewable Energy Certificates, and On-Site Renewable Generation**.[30]*

Additional information, tools, and technical support are available online from EPA's Green Power Partnership, a voluntary program to encourage green power procurement.[31]

A Sampling of Success Measures for Integrating Renewable Energy into Cleanups

- *Increased substitution of fossil fuels with fuel produced from renewable resources*
- *Lower emission of GHG, as well as particulate matter and other air pollutants*
- *Lower energy costs associated with petroleum fuel consumption*
- *Contributions to state renewable energy portfolios and national goals for energy independence*
- *Reduced loads on utility infrastructures*
- *Reduced environmental footprints associated with utility grid extension and road extension to remote sites*

Integrating Renewable Energy into Cleanup: Recommended Checklist

Maximizing Energy Efficiency and Monitoring Demand

- ✓ Conduct an energy audit
- ✓ Conduct prescribed maintenance and inspections
- ✓ Re-evaluate opportunities for system optimization
- ✓ Track energy consumption through tools such as plug-in meters and whole-system meter devices

Onsite Production of Renewable Energy

- ✓ Integrate renewable energy sources at various scales and from multiple resources
- ✓ Pursue opportunities to "scale up" and generate surplus electricity for credit or sale
- ✓ Explore creative financing techniques such as tax credits, rebates, and community partnerships

Renewable Energy Assessments

- ✓ Assure preliminary assessments are conducted by qualified personnel
- ✓ Maintain in-house experts to assist with assessment and follow-up purchasing and maintenance of systems

Economic and Technical Feasibility Studies

- ✓ Assure a thorough study that includes energy production estimates, O&M costs, and return on investment over the life of a system
- ✓ Examine other options such as energy production that is integrated within the existing utility structure or a PPA

Purchasing Clean Energy from Offsite Resources

- ✓ Voluntarily purchase clean energy as a substitute for onsite production or to supplement offsite production
- ✓ Select clean power products certified through an independent third-party program such as Green-e

EPA appreciates the many document contributions from project managers and others who are integrating renewable energy into site cleanup; contributing practitioners include representatives of EPA regional offices, AFCEE, USACE, and NY DEC.

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EPA is publishing this fact sheet as a means of disseminating information regarding the BMPs of green remediation; mention of specific products or vendors does not constitute EPA endorsement.

Visit *Green Remediation Focus* online:
http://cluin.org/greenremediation

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United States Environmental Protection Agency
Office of Solid Waste and Emergency Response (5102G)
EPA 542-F-11-008
June 2011

Green Remediation Best Management Practices:
Sites with Leaking Underground Storage Tank Systems

Office of Superfund Remediation and Technology Innovation — Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outline the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) identified in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis, while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.[2]

Core Elements of Green Remediation

- *Reducing total energy use and increasing the percentage of energy from renewable resources*
- *Reducing air pollutants and greenhouse gas (GHG) emissions*
- *Reducing water use and negative impacts on water resources*
- *Improving materials management and waste reduction efforts, and*
- *Protecting ecosystem services during cleanup*

Overview

Almost 495,000 releases of petroleum from federally regulated underground storage tanks (USTs) have been reported to EPA as of September 2010. Of these, over 93,000 UST site cleanups remain. The Association of State and Territorial Solid Waste Management Officials (ASTSWMO) estimates that cleaning up UST system releases costs the states approximately $700 million each year,[3] in addition to federal expenditures under the Leaking Underground Storage Tank (LUST) Trust fund and costs paid by responsible parties.

State agencies maintain responsibility to implement and oversee corrective actions at UST sites, with the exception of federal authority for UST site cleanup in Indian country. The majority of these actions involve UST systems for petroleum fuel rather than chemicals containing hazardous substances and most involve retail fueling stations. Common contaminants associated with fuel releases include benzene, toluene, ethylbenzene, and xylenes (BTEX) and sometimes other chemicals of concern such as methyl *tert*-butyl ether (MTBE), ethanol, or lead scavengers (ethylene dibromide and 1,2-dichloroethane).

Releases of petroleum, used oil, or chemicals can result from problems such as corrosion of the tank or attached pipes, structural failure, or faulty installation. In addition to the tank, components of an UST system include connected underground piping, underground ancillary equipment, and the containment system, if any.

*An UST cleanup that involves **excavating** 5,000 cubic feet of soil and **operating a soil vapor extraction system** over three years for deeper soil could emit **190 tons of carbon dioxide equivalent,** approximately the same amount emitted through electricity consumption of 21 homes over one year.*

Use of green remediation BMPs to remediate these sites can help minimize the environmental footprint of cleanup activities and improve corrective action outcomes. The practices for UST cleanups are intended to complement rather than replace federal requirements for corrective actions (40 CFR Part 280, subpart F). The practices also may enhance state-administered UST programs, which have state-specific corrective action requirements.

*"All cleanup approaches, and all elements of the cleanup process, can be optimized to enhance their overall environmental outcome; therefore, **green remediation involves more than merely adopting a specific technology or technique**."* EPA Principles for Greener Cleanups[1]

Many green remediation BMPs are standard operating procedures that are borrowed from the construction, industrial, and other business sectors working to reduce their environmental footprint. Some involve little or no additional cost while others may involve initial expenditures that can be recovered over the life of a cleanup project. EPA recognizes that project management discretion is involved when comparing the technical feasibility as well as the cost of implementing some BMPs at a given site. Applicability of each BMP may also differ due to variability in site conditions such as the type of stored liquid, UST system size, or anticipated site reuse.

EPA encourages UST cleanup project managers to procure services from contractors, environmental or engineering consultants, and laboratories demonstrating a commitment to the core elements of green remediation. Opportunities to reduce the environmental footprint of cleanup are found during each major phase of activity:

- ***Characterizing the site***
- ***Removing or replacing a tank system***, and
- ***Remediating contaminated environmental media.***

Characterizing the Site

Integrating green remediation ("greener cleanup") BMPs early during the initial response, investigative, and project design phases can help reduce the cumulative footprint of an UST cleanup. *Site investigation BMPs* include:

- Using dynamic, real-time decision-making strategies such as Triad to minimize energy and other resources needed for field mobilization and sampling efforts[4]
- Deploying geophysical tools such as ground penetrating radar or electromagnetic surveys to define boundaries of buried tanks without disturbing land
- Maximizing use of portable meters with photoionization or flame ionization detectors to screen soil cuttings or sample cores for contaminant presence, to efficiently locate materials needing excavation and minimize initial needs for sample analysis by offsite laboratories
- Selecting direct push (DP) tools to collect subsurface samples wherever site conditions allow, rather than conventional drilling systems that typically involve more fuel consumption, land disturbance, and investigation-derived waste
- Equipping DP tools with real-time qualitative tools such as membrane interface probes or laser induced fluorescence, wherever warranted by site complexity, to additionally reduce remobilizations and investigation-derived waste generation
- Using field test kits that minimize needs for offsite analysis of samples and selecting test kits that generate minimal waste
- Integrating remote sampling approaches such as solar-powered telemetry systems to reduce field trips, and
- Deploying mobile laboratories to reduce off-site sample analysis if a high volume of samples is anticipated.

Other techniques resulting in a smaller footprint of field activities include:

- Choosing biodegradable hydraulic fluids on hydraulic equipment such as drill rigs
- Using closed-loop cleaning systems relying on graywater to wash non-sampling related machinery and equipment
- Steam-cleaning or using phosphate-free detergents instead of organic solvents or acids to decontaminate sampling equipment
- Containing decontamination fluids and preventing their entrance into storm drains or the ground surface, and
- Segregating and stockpiling drill cuttings for potential onsite distribution of clean soil.

Additional BMPs are described in EPA's companion fact sheet, *Green Remediation Best Management Practices: Site Investigation*.[5a]

BMPs for *green purchasing* may be introduced to an UST cleanup project during the investigative phase and carried forward to cleanup activities. For example, project managers can:

- Choose products manufactured through processes involving nontoxic chemical alternatives
- Select products with recycled and biobased contents such as agricultural or forestry waste instead of petroleum-based ingredients; EPA offers recycled product listings and procurement guidelines specific to construction, landscaping, and other materials markets[6]
- Use products, packing material, and disposable equipment with reuse or recycling potential
- Use the Electronic Product Environmental Assessment Tool (EPEAT®)[7] to find electronic products with reduced impacts on the environment and Energy Star® ratings on energy efficiency of other products,[8] and
- Select locally made materials whenever possible.

Other BMPs concerning *project administration* include:

- Establishing reduced paperwork systems such as electronic networks for data transfers and deliverables, team decisions, and document preparation
- Reducing travel through increased teleconferencing, and selecting hotel and meeting facilities with green policies when project meetings are needed, and
- Establishing simple record-keeping procedures for green remediation measures such as fuel consumption, groundwater replenishment, and material recycling.

EPA Region 9 investigation of LUST-contaminated soil and groundwater affecting Navajo Nation and Hopi Tribe tribal lands near Tuba City, AZ, involved use of a conceptual site model and mobile laboratory to guide subsurface application of food-grade vegetable oil that accelerated bioremediation of contaminated soil.

BMPs regarding *onsite and offsite transportation* can help reduce the environmental footprint of UST system removals and follow-on site remediation. Opportunities to reduce air pollutant emission from internal combustion engines in vehicles and stationary sources involve identifying local service providers who maximize use of:

- Operation and maintenance plans resulting in lower consumption of petroleum fuel, such as standard operating procedures to reduce engine idle
- Advanced diesel technologies such as diesel oxidation catalysts, diesel particulate matter filters, and partial diesel particulate filters
- Fuel efficient and alternative vehicles such as plug-in electric vehicles for onsite data collection and hybrid

electric vehicles for longer offsite travel; EPA's *Green Vehicle Guide* can help decision-makers evaluate the options when choosing vehicles,[9] and
- Alternative fuels and fuel additives, including biodiesel blends and ultra low-sulfur diesel for all diesel-powered machinery and equipment.

Other methods to reduce liquid fuel consumption and air emissions during UST site cleanup involve increased substitution of petroleum fuel with sources of renewable energy, particularly for powering remediation components or auxiliary equipment with a low energy demand. A small off-grid wind turbine and/or or photovoltaic (PV) system, for example, can be equipped with deep-cycle batteries to provide relatively steady power.

Electricity for various needs can be generated onsite by mobile systems that capture renewable energy.

Recovery of petroleum products from groundwater at the former Adak Naval Complex in Alaska was powered by a mobile wind turbine.

Details on benefits, costs, and other factors that can help managers select and implement the most suitable methods to reduce transportation-related footprints are provided in EPA's *Green Remediation Best Management Practices: Clean Fuel & Emission Technologies for Site Cleanup*.[5b]

Decision-makers can also investigate methods for reducing air emissions caused by *long-distance transport* of incoming materials or outgoing waste, such as:

- Procuring services or materials from partners or affiliates in EPA's SmartWay transport partnership[10]
- Considering railroad instead of truck transport, and
- Consolidating deliveries and schedules to avoid deploying partially filled trucks.

Removing or Replacing a Tank System

A major contributor to the environmental footprint of an UST cleanup is the deployment of heavy machinery for excavation, tank system removal, and site restoration. Many related BMPs are described in EPA's *Green Remediation Best Management Practices: Excavation and Surface Restoration*.[5c] Selection of suitable BMPs when removing an UST system during site cleanup may be affected by conditions such as groundwater depth, soil permeability, and subsurface rock types. Greener cleanup BMPs applying to *UST removals* include:

- Segregating and stockpiling excavated soil and material that is clean or minimally contaminated for beneficial reuse
- Covering ground surfaces with re-useable tarp in areas used for fluid extraction and transfer
- Minimizing the volume of water used for rinsing a tank (where allowed by state and local agencies) prior to removal, to generate less waste water
- Flushing system pipes with nitrogen instead of water to reduce waste generation
- Controlling odor and fugitive dust by applying bio-degradable foam on equipment and soil surfaces
- Transferring extracted fuel or chemicals to local recyclers who use environmentally sound procedures, and
- Disposing tanks, piping, and other metal components at a state-approved or -certified tank disposal yard for recycling instead of a landfill.

Surgical excavation and tank removal at the G&L Clothing site in Illinois allowed for minimal site disturbance and maximum recycling or reuse of excavated materials.

Profile: G&L Clothing Cairo, IL

- *Planned investigative and remedial activities that minimized mobilization of staff and equipment for removing two 1,000-gallon gasoline USTs and one 5,000-gallon diesel UST from an abandoned gasoline station*
- *Reduced offsite transportation and associated resources by maximizing deployment of local workers and suppliers*
- *Reduced the number of investigative samples by holistically approaching the target area as a single tank pit rather than three adjacent pits*
- *Conserved fuel by placing engine idle restrictions on construction equipment*
- *Reduced air emissions by using an excavator equipped with emission controls meeting EPA Tier II standards for non-road diesel equipment*
- *Avoided unnecessary double-crushing of excavated materials by loading excess concrete directly from the excavation pit into dump trucks*
- *Reclaimed the excavated tanks for recycling by a local auto salvage business, and*
- *Minimized the amount of imported soil needed as backfill during site redevelopment (for a retail clothing store) by reusing approximately 50 tons of demolition concrete that was crushed onsite*[11]

Cleanup activities that involve removing an UST system are often integrated with site plans to continue using an underground storage facility for industrial or retail purposes. *Tank system replacement* steps that could be taken by owners and operators to minimize potential for petroleum or chemical releases and improve release detection could include:

- Avoid interior lining of tanks or use cathodic protection when lining is in place
- Use secondarily contained tanks and piping
- Use tanks and piping made of steel that are coated and cathodically protected, tanks and piping made of non-corrodible materials, or tanks that are not subject to exterior corrosion (such as clad or jacketed steel tanks)
- Avoid ball floats as a means to prevent tank overfills
- Install upgraded alarm systems
- Increase the frequency of cathodic protection system tests
- Check release detection equipment at least annually according to manufacturer recommendations
- Avoid reliance on groundwater or soil vapor monitoring results as a means of leak detection, and
- Institute non-cumbersome "paper trails" that can facilitate stronger environmental stewardship among short- or long-term UST owners and operators.

Current protocols for release detection systems do not address ethanol blended fuels available in today's market. Information about selecting leak detection technologies for ethanol blends is available in a new quality assurance plan available from EPA's Environmental Technology Verification (ETV) Program.[12] The National Renewable Energy Laboratory offers additional information about biodiesel storage, handling, and use.[13] EPA is developing guidance on the compatibility of UST systems with biofuels, including ethanol-blended fuels containing greater than 10% ethanol; release of the guidance is expected in 2011. Some states also have policies in place regarding ethanol-blended fuel storage.

Important BMPs for restoring land following tank system removal or replacement include:

- Using native species of plants for revegetation, which typically need little or no maintenance such as irrigation
- Finding beneficial use for woody debris, such as onsite or offsite landscaping or habitat creation
- Using low impact development techniques such as creating bioswales to reduce water runoff, and
- Using pervious construction materials for vehicle or pedestrian traffic areas to increase water infiltration to the subsurface of redeveloped sites.

Remediating Contaminated Environmental Media

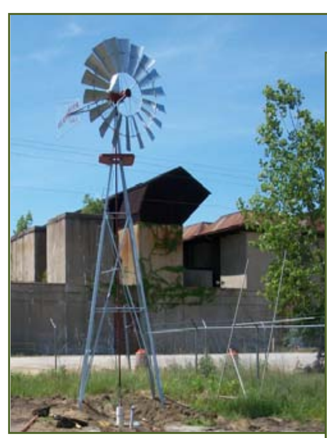
Technologies used for UST cleanups often involve one or a combination of technologies such as groundwater pump-and-treat systems, soil excavation and disposal, soil vapor extraction, air sparging, bioventing, bioremediation, dual-phase extraction, and in situ chemical oxidation.[14] EPA's Office of Superfund Remediation and Technology Innovation (OSRTI) offers companion fact sheets detailing green remediation *BMPs tailored to cleanup technologies*:

- *Pump and Treat Technologies*[5d]
- *Bioremediation*,[5e] and
- *Soil Vapor Extraction & Air Sparging*.[5f]

Decisions on how to implement these and other technologies can be enhanced by assessing their environmental footprint on a site by site basis. The *Green Remediation Focus* Web site sponsored by OSRTI offers a compendium where over 50 free tools such as online calculators and software can be easily accessed to assess one or more elements of a greener cleanup.[15] Other online material includes site-specific results of applying a footprint assessment methodology designed by EPA to include all elements of a greener cleanup, as outlined in the Agency's *Principles for Greener Cleanups*. Organizations conducting or managing multiple UST cleanups with similar site conditions may save resources by also using these tools and examples to select a suite of BMPs that form a technology implementation model.

The environmental outcome of UST site cleanups through use of nearly any technology may be improved through *general BMPs for remediation*:

- Considering tradeoffs associated with energy use and air emissions when evaluating the potential for leaving waste in place at a portion of the site, if site-specific risk criteria can be met with minimal institutional controls
- Assuring proper sizing of remediation equipment that allows minimal rates of energy consumption while sustaining the target cleanup pace
- Periodically reassessing and optimizing existing treatment systems to maintain peak operating performance and identify opportunities for taking any equipment offline as cleanup progresses
- Developing an infrastructure for the remedial system that can be integrated with site reuse
- Switching to a "polishing" remedy once effectiveness of an existing treatment system declines, as evidenced by significant decreases in mass recovery rates, and
- Recovering and recycling separated non-aqueous phase liquid (NAPL) through local fuel or waste recyclers.



Two 21-foot windmills provide mechanical power to extract groundwater for light NAPL recovery at the Hanover brownfield site in South Bend, IN, which was contaminated by two fuel USTs; capture of wind energy avoids the need for two 1-horsepower pumps and reduces consumption of grid electricity by at least 1.5 kW.

Project managers are encouraged to implement an UST remediation *monitoring plan* that reflects BMPs such as:

- Establishing a schedule for environmental sampling that minimizes frequency of sampling events while assuring cleanup progress
- Evaluating environmental monitoring results on a regular basis (possibly quarterly) to identify opportunities for reducing or eliminating unnecessary analyses
- Using remote monitoring techniques to assure effective operation of treatment systems with fewer site trips, and
- Seeking opportunities for integrating remediation monitoring with future use of the site.

An off-grid PV system at Brooks Camp, AK, powered an air sparging pump that operated only during daylight hours, which sufficiently treated contaminated groundwater while avoiding energy loss and freeze potential associated with battery storage.

Profile: Brooks Camp, Katmai National Park and Preserve, AK

- *Minimized land disturbance during remedial construction in this archeologically and biologically sensitive property of the National Park Service (NPS) by surgically removing vegetation in the treatment area and using compact designs*
- *Began operating an in situ remediation system in 1998 involving bioremediation (via injection of oxygen releasing compounds), air sparging, and bioventing to treat soil and groundwater contaminated by two former petroleum LUSTs*
- *Optimized energy use through treatment design allowing use of a single 1.5-horsepower blower to alternately operate the air sparging and bioventing equipment in four-hour increments*
- *Housed the aboveground mechanical equipment in a prefabricated treatment shed with south-facing windows that provide interior daylighting*
- *Eliminated unnecessary energy consumption by taking the bioventing system offline after two years of operation, when sampling indicated a source reduction in diesel-range organics to below cleanup levels set by the Alaska Department of Environmental Conservation*
- *Installed an onsite, 770-watt PV system in 2000 for powering the air sparging pump, to avoid continued use of the site's diesel-powered generator and assure ongoing treatment operations at this remote location, and*
- *Began re-purposing the PV system in 2006 (when cleanup goals were met and the system was no longer needed for remediation) to meet other critical energy needs evolving at Brooks Camp*[16]

Similar or additional green practices established by other federal or state programs and sectors also can be explored. For example, EPA recommends incorporation of green practices into construction projects funded through the American Recovery and Reinvestment Act (ARRA) of 2009, many of which involve UST site cleanup. In addition to incorporating EPA's recommendations, some states maintain supplemental criteria applying to UST cleanups. The Minnesota Pollution Control Agency, for example, requests contractors and vendors at ARRA-funded LUST sites to report on use of greener cleanup practices for purchasing, transportation, field and laboratory work, and materials and waste management.[17]

Another example is the Smart Growth Network, which identifies principles that can minimize air and water pollution and preserve natural lands during property development.[18] Implementation of the principles at UST sites can help integrate a greener cleanup into site reuse. As a member of the network, EPA offers technical assistance and funding to organizations and communities working toward smart growth and sustainability.

Sustainable redevelopment of a remediated brownfield site formerly used as a gasoline station in Eugene, OR, focused on building a biofuel station with solar power along with low impact development elements such as bioswales; the biofuel is made of discarded cooking oil collected across the state.

Lane County-Sequential Biofuels, 2007 Phoenix Award

A Sampling of Success Measures for UST Site Cleanup

- *Reduced land disturbance during site investigation due to substitution of exploratory excavation or drilling with advanced geophysical techniques*
- *Lower emission of GHG, particulate matter, and other air toxics due to fewer field mobilizations and associated fuel consumption*
- *Beneficial use of local industrial or agricultural waste as reactive media for onsite soil treatment*
- *Higher percentages of demolition material transferred to recycling facilities instead of municipal landfills*
- *Beneficial use of treated groundwater for onsite purposes such as irrigation rather than treatment-water discharge to a public sewer system*
- *Increased offsets of air emissions and lower monthly utility costs due to capture of onsite renewable energy*

UST Site Cleanup: Recommended Checklist

Characterizing the Site

- ✓ Use investigative techniques involving minimal land disturbance, field mobilization, and waste generation
- ✓ Employ green purchasing techniques for products and services
- ✓ Institute greener methods for project administration and accounting
- ✓ Establish mechanisms to assure use of EPA's BMPs for using clean fuel and emission technologies throughout the project

Removing or Replacing a Tank System

- ✓ Use surgical excavation techniques that minimize land disturbance
- ✓ Prevent spillage and control odors and fugitive dust when emptying a tank and recycle all reusable fluids
- ✓ Use advanced equipment for release prevention and detection when replacing an UST system as part of integrated site remediation and redevelopment
- ✓ Restore excavated areas quickly with native plants or pervious ground covers, depending on site reuse

Remediating Contaminated Environmental Media

- ✓ Employ EPA's BMPs for commonly used remediation technologies such as pump-and-treat systems, bioremediation, and soil vapor extraction
- ✓ Optimize remedial operations through proper equipment sizing and frequent reassessment
- ✓ Establish operating or performance criteria that could trigger use of less intensive polishing technologies as cleanup progresses
- ✓ Substitute electricity drawn from the utility grid with power generated by onsite renewable energy resources
- ✓ Deploy long-term monitoring techniques that rely on remote sensing/control technology, with potential integration into site reuse

EPA and state organizations offer *additional resources* to help project managers reduce the environmental footprint of UST corrective and remedial actions:

- EPA's *Greener Cleanups Contracting and Administrative Toolkit*, which contains samples of specifications used by EPA regions and other government agencies in cleanup service contracts, records of decision, and other administrative documents[19]
- Information on green remediation and other UST initiatives of the ASTSWMO LUST Task Force and Greener Cleanup Task Force,[20] and
- Updated methods, resources, and guidance from EPA's Office of Underground Storage Tanks.[21]

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[a] *Site Investigation*; EPA 542-F-09-004, December 2009
[b] *Clean Fuel & Emission Technologies for Site Cleanup*; EPA 542-F-10-008, August 2010
[c] *Excavation and Surface Restoration*; EPA 542-F-08-012, December 2008
[d] *Pump and Treat Technologies*; EPA 542-F-09-005, December 2009
[e] *Bioremediation*; EPA 542-F-10-006, March 2010
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19 U.S. EPA; Office of Superfund Remediation and Technology Innovation; http://www.cluin.org/greenremediation/docs/Greener_Cleanups_Contracting_and_Administrative_Toolkit.pdf

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EPA appreciates the many document contributions from representatives of EPA regional offices or LUST Teams and ASTSWMO members.

The Agency is publishing this fact sheet as a means of disseminating information regarding the BMPs of green remediation; mention of specific products or vendors does not constitute EPA endorsement.

Visit *Green Remediation Focus* online:
http://cluin.org/greenremediation

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United States Environmental Protection Agency

Office of Solid Waste and Emergency Response (5102G)

EPA 542-F-11-024
December 2011

Green Remediation Best Management Practices:
Landfill Cover Systems & Energy Production

Office of Superfund Remediation and Technology Innovation — Quick Reference Fact Sheet

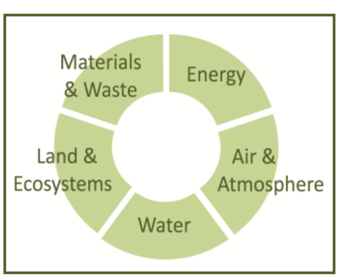
The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outline the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) recommended in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.

Remediation at thousands of sites across the United States involves hazardous waste from former industrial landfills or waste piles, aged municipal landfills, or illegal dumps. A cover system is commonly installed at these areas as part of proper closure to serve as a surface barrier that contains the source material, reduces contaminant exposure or migration, and manages associated risk. Also known as a cap or cover, a cover system is typically used where:

- A hazardous, municipal, or co-disposal landfill was created before the 1976 enactment of, and subsequent amendments to, the Resource Conservation and Recovery Act (RCRA)
- An existing unit such as a closed impoundment has been designated as a consolidation area or a decision is made to build a new onsite landfill, and/or
- Direct contact or groundwater leaching presents a risk.

Cover systems can benefit from innovative designs that increase long-term performance while reducing maintenance needs. When properly designed and maintained, a final cover system for a closed landfill or consolidation unit can also provide significant opportunities for site reuse (typically on a restricted basis).

The environmental footprint of activities needed to install and maintain a cover system can be reduced by adhering to EPA's ***Principles for Greener Cleanups***. The core elements of a greener cleanup involve:



- Reducing total energy use and increasing the percentage of renewable energy
- Reducing air pollutants and greenhouse gas (GHG) emissions
- Reducing water use and negative impacts on water resources
- Improving materials management and waste reduction efforts, and
- Protecting ecosystem services.

Green remediation BMPs for addressing landfills focus on:

- ***Designing and installing a cover system*** through approaches such as materials life cycle assessment for conventional covers or selection of alternative caps
- ***Landfill gas recovery for beneficial use*** as a renewable source of energy
- ***Integrating landfill cover designs with reuse*** of a site for generating energy from solar or wind resources or for other beneficial use, and
- ***Maintaining and monitoring a final cover*** through streamlined operation and maintenance (O&M) activities and automated equipment.

Landfills built to contain hazardous wastes are governed by Subtitle C of RCRA (40 CFR 264.300), while those constructed for non-hazardous waste such as municipal solid waste (MSW) are covered by RCRA Subtitle D (40 CFR 258). In addition to RCRA requirements, closure and capping of a landfill or former waste area can be subject to requirements of the Clean Air Act, Clean Water Act, and other federal, state, or local regulations. In cleanup programs such as Superfund, these regulations can be applied to parts of a remedy as applicable or relevant and appropriate requirements (ARARs).

Designing and Installing a Cover System

A Subtitle C or D ***conventional cover system***, also known as a barrier cover, is linked to the landfill liner system. This type of cover consists of a layer of compacted soil with permeability below or equal to that of the liner or the natural soils present (or for Subtitle D, permeability no greater than 1×10^{-5} cm/sec). Since the liner of a Subtitle C cover system often consists of a geomembrane, its corresponding cover needs to be constructed in a fashion resulting in equivalent permeability. Other layers for drainage or gas collection or to serve as a biobarrier can be added. ***Green remediation BMPs*** for designing and installing a conventional cover system include:

- Design in ways that mimic rather than alter the site's natural setting, to improve the cover's long-term

performance and protect ecosystem services[2] such as potable water, wildlife habitat, and carbon storage
- Design a cover accounting for potential effects of climate change, which could involve changes in onsite soil development or increased vulnerability to flooding
- Use uncontaminated soil or sediment from onsite excavation instead of imported soil/sediment for the cover's frost prevention and erosion control layers; similarly, uncontaminated sand, gravel, and rocks from onsite instead of offsite areas may be used for drainage
- Apply low impact development[3] strategies such as installing earthen berms to manage stormwater
- Choose geotextile fabric or drainage tubing composed of 100% recycled materials rather than virgin materials for lining, erosion control, and drainage
- Select materials with biobased content for daily activities during cover construction, including those designated for procurement by federal agencies[4]
- Use clean fuel and emission control technologies for routine field vehicles and machinery such as backhoes and bulldozers to reduce fuel consumption and emission of air pollutants such as GHGs and particulate matter,[5a] and
- Investigate onsite solar and wind resources to power equipment such as leachate pumps and flare units.

An ***alternative design*** for a landfill can be proposed in lieu of a RCRA barrier design if it demonstrates equivalent performance for criteria such as infiltration reduction and erosion resistance. Subtitle D landfill regulations also allow installation of equivalent alternative covers and innovative covers that support research. One alternative design involves covers composed of ***asphalt or concrete***. Systems based on this design are best applied to sites where minimal settlement is expected. BMPs to reduce the environmental footprint of this design include:

- Consider using asphalt rubber (containing recycled tires) where the cover system includes a layer of asphalt
- Substitute concrete with high albedo pavement, which reflects sunlight and heat away from the cover surface and may aid growth of nearby vegetation
- Consider using concrete containing a high percentage of industrial waste by-products as a substitute for cement, if tests show no contaminant leaching, and
- Use concrete wash-outs to assure proper disposal of mix water.

Another alterrnative design is an ***evapotranspiration (ET) cover system***, which prevents infiltration of water into the contained waste.[6] An ET cover relies on a thick soil layer with vegetative cover capable of storing water until it is transpired or evaporated. ET covers perform best in arid and semi-arid environments such as those found in parts of the Great Plains and western states.[7]

*A capillary barrier **ET cover** at the **Monticello Mill Tailings NPL Site** in Utah was designed to mimic the area's ecology and follow the natural progression of revegetation. Native species existing atop the cover after seven years include gray rabbitbrush and sagebrush.*

ET cover designs present two alternatives. A monolithic design uses a vegetated, relatively homogeneous, fine-grained soil layer to retain water and limit deep drainage. In contrast, a capillary barrier design consists of a fine-grained soil layer overlaying coarser material such as sand or gravel. The coarse layer forms a capillary break at the layer interface, allowing the fine-grained layer to retain more water than a monolithic cover system of equal thickness.

A capillary barrier ET cover system can be designed to enable the capillary break layer to act as a biobarrier or gas collection layer.

In addition to BMPs that apply to conventional covers, BMPs for designing and installing an ET cover include:

- Choose recycled (crushed) concrete for biobarriers or capillary breaks instead of natural rock
- Select native drought-resistant plants for the upper vegetative layer to reduce maintenance needs
- Preserve biodiversity and related ecosystem services by installing a suitable mix of native shrubs, grasses, and forbs, and
- Use nonsynthetic amendments such as compost instead of chemical fertilizers if the soil or vegetation is found to need supplementation over time.

Information on alternative landfill covers at more than 200 sites is available in EPA's alternative landfill database.[8] Additional BMPs that can apply at many landfills undergoing cover installation are described in *Green Remediation: Best Management Practices for Excavation and Surface Restoration*.[5b]

Landfill Gas Recovery for Beneficial Use

EPA encourages owners or operators of sites with landfills to use landfill gas (LFG) as a source of energy. Evaluating the options for a waste gas-to-energy system before, rather than after, waste is placed in a new landfill or consolidation unit can maximize this potential throughout the life of a landfill. Similarly, integration of the components for an LFG collection system into the design for a final cover at a closed landfill can help avoid later retrofitting and additional costs if site or administrative conditions change over time.

The capacity of LFG to provide useable energy generally depends on its proportion of methane, a potent GHG traditionally destroyed through combustion (flaring). LFG from recently closed MSW landfills with properly operated gas collection systems, for example, often contains 40-60% methane; the remainder consists primarily of carbon dioxide (CO_2), another GHG. As a landfill ages, its methane generation decreases at a rate depending on the volume and type of organic waste content and site conditions such as average rainfall. In contrast, an industrial landfill or a construction and debris landfill typically emits very little LFG throughout its life. Additional characteristics to consider when evaluating feasibility of an LFG-to-energy system include depth of the waste, impermeability of the cap and liner, and local electricity prices.

The global warming potential of methane is 21 times higher than that of CO_2.[9]

*As a small facility, the **Crow Wing County SLF** municipal landfill in Brainerd, MN, is not required to collect and combust its LFG. Accelerated generation of LFG after startup of the landfill's leachate collection system, however, led to voluntary installation of a 10-well LFG recovery system. With a throughput of only 30 standard cubic feet per minute (scfm), the LFG is now recovered for **direct use to fuel a boiler** that heats the facility's onsite buildings. Since 2009 installation of the LFG recovery system, the facility's natural gas consumption has decreased by nearly 70%. The County estimates a **$5,000 annual savings in utility costs** due to lower natural gas consumption and a return on the LFG recovery system investment within eight to nine years.*

With appropriate treatment, LFG can be channeled for ***direct use*** to power equipment operating on low or medium BTU gas (about 50% of the heating value of natural gas) for onsite operations. Medium BTU gas also could be piped to an adjacent facility to fuel equipment such as industrial boilers and cement kilns or to provide heating in commercial businesses such as plant nurseries. LFG can also be routed to internal combustion engines, turbines, or microturbines that ***generate electricity***. Internal combustion engines are typically the choice for LFG projects sized at 800 kW and larger, while microturbines are used for smaller projects (as little as 30 kW). Unlike most internal combustion engines, microturbines can operate with low LFG flow or methane content.[10] Most engines or turbines can be used singularly or in parallel configuration.

Points of Reference

- *LFG energy content varies but averages about 500 BTU/cubic foot.*
- *The output of one 30-kW microturbine can power a 40-hp motor.*
- *A 1-MW generator could meet the annual electricity needs of 1,070 U.S. homes.*

*The **Lowry Landfill Superfund Site** in Aurora, CO, occupies over 500 acres formerly used for municipal, hazardous, and industrial waste disposal. Contamination was partially addressed by constructing a conventional four foot-thick soil cover over the landfill. The landfill is located adjacent to the Denver Arapahoe Disposal Site (DADS), an active municipal landfill facility. Instead of being flared, the LFG from both sites is converted into electricity by **four internal combustion engines**. Since 2008, the Lowry Landfill/DADS landfill gas-to-energy plant has converted 630 million cubic feet of LFG into 3.2 MWh of electrical energy each year. The local utility distributes the generated electricity under a **renewable energy purchase agreement**.*

Electricity generated through these LFG recovery technologies can be used to:

- Power other landfill operations such as leachate collection and treatment systems
- Provide energy for long-term cleanup operations such as groundwater pump-and-treat systems, or
- Supplement the local utility grid through sale or credit mechanisms.

*Six 70-kW microturbines replaced the flaring system used to treat LFG at the **Operating Industries, Inc.** Superfund site cleanup project in Monterey Park, CA. The LFG was extracted at an average rate of 4,200 scfm, with a **methane content of 29-39%**. Upon turbine start-up, sufficient electricity was generated to meet approximately 70% of the 600-kWh demand made by the project's combustion blowers, thermal oxidizers, and auxiliary equipment. Over eight years of microturbine operations, the project realized cumulative net savings of $647,000.*

Selecting a suitable landfill gas-to-energy system considers the short- and long-term benefits gained by economy of scale and reductions in utility expenses.

Electricity Generation Technology	Typical LFG Flow Range (cubic feet per minute (cfm) at 50% methane)	Power Range (kW or MW)	Typical Capital Cost ($/kW)	Typical O&M Cost ($/kWh)
Internal Combustion Engine	38 - 1,140	100 kW - 3 MW	$2,000	$195
Turbine	1,300 – 2,100	800 kW - 10.5 MW	$1,400	$130
Microturbine	20 – 200	30 kW - 250 kW	$5,500	$380

Based on information in the Landfill Methane Outreach Program "Project Development Handbook"[11]

These technologies may also ***produce waste heat*** that can be captured and used to generate combined heat and power (CHP). In addition to providing heat for buildings, water, or industrial processes, CHP could produce steam (from a gas turbine) which in turn can power a steam generator to produce more electricity.

LFG can also be processed on site to remove oxygen, CO_2, nitrogen, and other trace gases to ***produce fuels*** with a high BTU content, such as pipeline-quality gas, compressed natural gas (CNG), and liquefied natural gas. An auto manufacturing plant at a former brownfield in Orion, MI, for example, relies on LFG from neighboring landfills as a substitute for natural gas in a significant portion of the plant operations.

CNG Production from LFG[11]		
LFG Flow (scfm)	Production Volume (gallons of gasoline equivalent (GGE)/day)	Cost ($/GGE)
250	1,000	$1.40
500	2,000	$1.13
1,250	5,000	$0.91
2,500	10,000	$0.82
5,000	20,000	$0.68

Cleanup managers may explore these opportunities by:

- Applying EPA's Landfill Gas Energy Screening Tool to initially screen the potential for landfill methane recovery, associated cost, technical practicality, and anticipated reduction in GHG emissions[12]
- Working closely with potentially responsible parties (PRPs) and owners or operators to design and implement methane recovery projects on a voluntary basis
- Procuring technical assistance from experts experienced in LFG energy systems to evaluate feasibility at sites where initial screening indicates significant potential
- Engaging utilities or developers for sites with potential to generate "excess" electricity (beyond onsite needs) that contribute to state renewable energy portfolios
- Soliciting partners to demonstrate technologies that are emerging for electricity generation from LFG, such as Stirling engines (external combustion engines), organic Rankine cycle engines, and fuel cells,[13] and
- Using energy savings performance contracts to finance and obtain technical assistance for LFG projects undertaken by federal agencies.[14]

Information to help evaluate the options is available from EPA's Landfill Methane Outreach Program (LMOP); the program's tools include the *Landfill Gas Energy Project Development Handbook* and decision-making software.[15] Continuously updated information about state, local, utility, and selected federal incentives promoting LFG as a source of renewable energy is available from the Database of State Incentives for Renewable Energy.[16]

*A system to recover LFG at the **Grand River Landfill** in Grand Ledge, MI, has expanded twice since 1990 start-up to become a 4.0-MW electricity generator. The system relies on 189 horizontal and vertical wells that transfer LFG to a power plant adjacent to this active MSW landfill, which includes closed treatment cells for coal-burning ash. The plant uses five 800-kW internal combustion engines fueled by LFG averaging 1,350 scfm, with a steady **51% methane content**. About 5% of the generated electricity is used to operate the plant and the remainder is sold to the local utility. Six mechanical **windmills** drive pumps that remove the waste cell leachate, which is treated onsite before discharge to the sanitary sewer.*

Integrating Landfill Cover Designs with Reuse

The options for reuse activities, which in some cases involves long-term cleanup in other areas of a site, can take advantage of ***contact covers.*** These cover systems are designed to create a biobarrier against intrusion by people, animals, and in some cases vegetation. This type of cover is generally used with metal contaminants but can also be used for organic contaminants with low mobility. Depending on site-specific reuse goals, contact covers can be constructed of asphalt, concrete, or soil.

When properly designed, landfill covers can provide significant opportunities to host economic enterprises such as ***power production from solar and wind resources***. EPA, other government agencies, and developers have begun investigating the potential for reusing formerly contaminated lands and mining properties on a large-scale basis. EPA's RE-Powering America's Land initiative has tracked this potential at sites across the United States.[17]

EPA recommends that designs for solar farms atop closed and properly covered landfills consider technical aspects such as weight of ***photovoltaic (PV) or concentrated solar power*** equipment, landfill cover thickness, waste settlement, wind or snow loading, and cover maintenance requirements.[18] Project planners also need to account for potential challenges such as ongoing cleanup activities or liabilities.[19]

*A **1.48-MW solar farm** began operating in late 2010 above the 28-acre ET cover at "Site 7" of the **Box Canyon Landfill** at Marine Corp Base Camp Pendleton, CA. The farm comprises 225 fixed-tilt PV panels in a 28-module configuration covering six acres. Each panel is mounted on a self-ballasted, non-penetrating foundation spaced sufficiently apart from others to accommodate vegetation maintenance and other cover requirements specified in the site's record of decision. Over the first year of operation, the PV system produced over 2,425 MWh of electricity for transmission to the local utility. This resulted in an electricity savings of about $340,000, demand savings of about $95,000, and an estimated* CO_2 *offset exceeding 1,540 tons. More solar energy will be captured through solar farm expansion and **solar-powered ignition systems** for LFG vents.*

Another option is use of a ***solar geomembrane cover***, which can meet Subtitle D alternative cap requirements while converting solar energy to useable power. A solar geomembrane cover also can be integrated with a LFG recovery system to maximize production of electricity from renewable resources.

*The landfill cover system at the **Hickory Ridge Landfill** in Conley, GA, relies on a 60-mil reinforced, synthetic membrane covering 45 acres. The exposed geomembrane overlays 12 inches of an intermediate cover and a compacted grading layer. Approximately 7,000 flexible **PV panels are bonded to the membrane**, which is positioned on about 10 acres with 18° southern and western slopes. Power cables in flexible conduit extend to the edge of the cap where they connect to an inverter. The 1-MW facility is expected to annually generate 1.3 million kWh of electricity that will be sold to the local utility under a renewable energy purchase agreement.*

Depending on the cover type, project managers can explore ***other compatible uses of land*** with properly covered landfills, such as:

- Greenspace for wildlife preservation or recreation[20]
- Agriculture such as hay production, and
- Seed harvesting to revegetate other sites.

Project managers also can explore approaches for recycling portions of the onsite waste, as an alternative to capping that provides economic and land use benefits. Cleanup at the Fairmont Coke Works-Sharon Steel Site in Fairmont, WV, for example, involves excavating, sorting, and blending the various consitutents to form feedstock sold to a local synfuel power plant.

Waste not contained in landfills or in disposal pits but left in place may provide other reuse opportunities while significantly reducing land and ecosystem disturbance during cleanup. This approach requires assessment of potential human health risk posed by the remaining hazardous substances or constituents and likely involves long-term institutional controls, restricted use, and ongoing liability to site owners.[21] Low human health risk at a high-elevation mining site, for example, may not affect anticipated use of a site for purposes such as community recreation or power production from renewable resources.

*In 2007, a **2-MW solar farm** was installed atop a 12-acre monolithic **ET cover** for construction debris at **Fort Carson**, CO. The design included selecting a native seed mix that would yield shade and drought-tolerant vegetation with a short height. **Monitoring and O&M** indicates more successful vegetative growth in areas shaded by the ground-mounted PV panels than in non-shaded areas, with no evidence of erosion caused by the panels. Vehicle traffic inside the fenced solar farm is kept to a minimum to avoid land disturbance, particularly under wet conditions. No irrigation has been needed despite the site's semi-arid climate, and no chemical pesticides/herbicides have been applied.*

*One round of early summer mowing to a four-inch height is typically sufficient to control weeds, minimize wildfire fodder, allow year-round light access across the site, and prevent shading of the PV panels. Periodic hand-washing of the solar modules is performed by using low-pressure hosing and heavily diluted vinegar. This **maintenance is performed by the solar developer** (Conergy) under a 20-year contract with Carson Solar I, LLC, the project owner. In return, the owner sells the generated electricity to Fort Carson at a reduced rate under a 20-year power purchasing agreement.*

Monitoring and Maintaining a Final Cover

Proper O&M of a cover system and landfill closure elements such as a gas collection system is needed to ensure they are performing as intended. Monitoring and maintenance BMPs can involve simple but efficient procedural changes as well as advanced field equipment to increase efficiencies, such as:

- Minimize frequency of grass mowing, to reduce fuel consumption and disruption to ground-nesting birds
- Explore using controlled grazing by goats or sheep to eliminate woody growth and control vegetation height while adding organic matter to the soil
- Integrate onsite structures to capture rainfall as a source of water for work such as rinsing field equipment
- Use remotely controlled or non-invasive techniques, to avoid cover damage and minimize field visits; for example, open path spectroscopy techniques can be used to periodically check for escaping LFG[22]
- Explore onsite renewable energy to power auxiliary equipment such as weather stations, and
- Evaluate natural settings as indicators of long-term changes in the cover.

EPA encourages PRPs and owners or operators of sites requiring landfill cover installation to work closely with states and other agencies or organizations responsible for oversight of the system over time (commonly 30 years or more) and any site reuse. Partners may include non-profit groups serving the local or regional community.

Landfill Cover Systems & Energy Production: Recommended Checklist
Designing and Installing a Cover System
✓ Design with the intent of maintaining natural settings and addressing potential effects of climate change
✓ Maximize use of onsite rather than offsite materials
✓ Maximize use of materials with recycled or biobased content
✓ Reduce consumption of petroleum-based power through clean fuel/emission technologies and renewable energy resources
Landfill Gas Recovery for Beneficial Use
✓ Explore opportunities for direct use of treated LFG
✓ Install LFG recovery technologies to generate electricity and use any associated waste heat
✓ Partner with other organizations to produce fuel
Integrating Landfill Cover Designs with Reuse
✓ Consider a contact cover to serve as a biobarrier
✓ Explore electricity production from solar and wind resources, for onsite use or credit/sale
✓ Identify other activities that could maximize use of a covered area without jeopardizing the cover system
Maintaining and Monitoring a Final Cover
✓ Schedule periodic inspection of cover system components and quickly complete needed repair
✓ Use non-disruptive techniques and the site setting to monitor cover system performance
✓ Explore partnerships to integrate cover maintenance with site reuse

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EPA/OSWER appreciates the many contributions to this fact sheet, as provided by EPA regions and laboratories or private industry.

The Agency is publishing this fact sheet as a means of disseminating information regarding the BMPs of green remediation; mention of specific products or vendors does not constitute EPA endorsement.

Visit **Green Remediation Focus** online:
http://www.cluin.org/greenremediation

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Office of Solid Waste and Emergency Response (5102G)

EPA 542-F-12-023
March 2012

Green Remediation Best Management Practices: Overview of EPA's Methodology to Address the Environmental Footprint of Site Cleanup

Office of Superfund Remediation and Technology Innovation — Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outline the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) recommended in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.

Remediation is underway or planned at thousands of sites across the United States under cleanup programs administered by government agencies and through voluntary efforts of site owners or operators. The activities needed to treat, contain, or otherwise address contaminated soil, water, and other environmental media and restore a site to productive use can collectively leave an environmental footprint. Cleanups involving complex activities may benefit from a detailed footprint analysis to inform decision-making about application of suitable BMPs for greener cleanups. EPA's **Methodology for Understanding and Reducing a Project's Environmental Footprint** identifies metrics associated with this footprint and a specific process to quantify or qualify those metrics.

The methodology adheres to EPA's *Principles for Greener Cleanups*, which involve five core elements:

- Reducing total energy use and increasing the percentage of renewable energy
- Reducing air pollutants and greenhouse gas (GHG) emissions
- Reducing water use and negative impacts on water resources
- Improving materials management and waste reduction efforts, and
- Protecting ecosystem services.

EPA developed the methodology (as documented in EPA report 542-R-12-002) as a means to encourage environmentally friendly behaviors on the part of decision-makers and day-to-day staff involved with site cleanup. It is designed to identify the most significant contributors to a project's environmental footprint and help integrate associated reduction parameters into conceptual design, construction, and operation of the project. EPA does not require environmental footprint analysis of cleanup activities but prefers use of the methodology when an analysis is conducted. Voluntary use of the methodology to varying degrees during any stage of cleanup may improve the project's environmental outcome.

EPA began developing the methodology in 2009 in order to identify a single, comprehensive set of metrics that could apply to most sites. Establishment of the methodology was also a strategic action outlined in the Agency's 2010 *Superfund Green Remediation Strategy*.[2] To test and refine proposed metrics and processes, the Agency conducted multiple pilot studies for RCRA corrective actions and Superfund remedial actions. Detailed information on three studies overseen by EPA Region 9 is available online.[3] In September 2011, the draft methodology also was made available to the public for review and feedback.

The methodology provides a **roadmap** to quantify the project's environmental footprint. The quantified information can then be used to identify opportunities for adjusting the project's operating parameters and applying BMPs in ways that reduce the footprint.

The process for conducting a footprint analysis following the methodology involves seven general steps:

1) Determining the goals and scope of the analysis, which vary with the remedial stage and site-specific factors
2) Gathering information about design, construction, and operation of the site's existing or anticipated remedy
3) Quantifying the onsite materials and waste metrics, which account for the materials used, the recycled content of those materials, various wastes generated, and portions of the waste that are recycled or reused
4) Quantifying the onsite water metrics, which consider the source and amount of water used on site as well as the fate of water after use
5) Using the combined information to quantify energy metrics and air metrics, which jointly consider the total amount of energy used (including the portion from renewable resources) and the air emissions associated with energy usage, onsite activities, and offsite support
6) Qualitatively describing ecosystem services that are affected during remedy implementation, and
7) Presenting results of each previous step and the overall results of analysis.

Access EPA's in-depth methodology report online at: http://www.clu-in.org/greenremediation/methodology

EPA's methodology report includes sample approaches to reducing environmental footprints of projects involving pump-and-treat, in situ chemical oxidation, and bioremediation technologies or excavation. In addition, its appendices provide:

- Seventeen exhibits containing planning checklists along with user-friendly reference tables on aspects such as common conversion factors, contents of materials frequently used for cleanup, and typical energy demands of equipment deployed in the field
- A series of detailed tables illustrating potential formats for organizing raw data and quantified estimates and for presenting overall results of footprint analysis, and
- Several scenarios illustrating use of the methodology to quantify the environmental footprint of a cleanup.

Based on results of the pilot projects and input from cleanup project managers, EPA selected 22 metrics for estimating the project footprint (as summarized below). Users may wish to supplement this set of metrics with additional ones meeting project or organizational needs and to tailor the presentation of footprint analysis results accordingly. The Agency's rationale for selecting each of these metrics is provided in the methodology report.

Summary of Environmental Footprint Metrics

Core Element	Metric	Unit of Measure
Materials & Waste (M&W)	M&W-1. Refined materials used on site	Tons
	M&W-2. % of refined materials from recycled or waste material	%
	M&W-3. Unrefined materials used on site	Tons
	M&W-4. % of unrefined materials from recycled or waste material	%
	M&W-5. Onsite hazardous waste disposed of off site	Tons
	M&W-6. Onsite non-hazardous waste disposed of off site	Tons
	M&W-7. % of total potential waste recycled or reused	%
Water (W)	Onsite water used (by source)	
	▪ W-1. Source, use, fate combination #1	Millions of gallons
	▪ W-2. Source, use, fate combination #2	Millions of gallons
	▪ W-3. Source, use, fate combination #3	Millions of gallons
	▪ W-4. Source, use, fate combination #4	Millions of gallons
Energy (E)	E-1. Total energy used	MMBtu
	E-2. Total energy voluntarily derived from renewable resources	
	▪ E-2A. Onsite generation or use and biodiesel use	MMBtu
	▪ E-2B. Renewable electricity purchase	MWh
	▪ E-2C. Purchase of renewable energy certificates (RECs)	MWh
Air (A)	A-1. Onsite NOx, SOx, and PM emissions	Pounds
	A-2. Onsite HAP emissions	Pounds
	A-3. Total NOx, SOx, and PM emissions	Pounds
	A-4. Total HAP emissions	Pounds
	A-5. Total GHG emissions	Tons CO_2e
Land & Ecosystems	Qualitative description	

The series of technical tables appending the methodology report provides potential formats for data management. Use of these formats can help decision-makers understand the relationships among activity-specific data, identify activities with the largest footprints, and map various opportunities to reduce the overall project footprint.

Considerations when interpreting final results of footprint analysis include:

- Goals of the analysis
- Data quality
- Tradeoffs between metrics, and
- Magnitude of the footprint.

[1] U.S. EPA; *Principles for Greener Cleanups;* August 27, 2009; http://www.epa.gov/oswer/greenercleanups
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[3] U.S. EPA; CLU-IN Green Remediation Focus; Footprint Assessment; http://www.cluin.org/greenremediation/subtab_b3.cfm

Visit Green Remediation Focus online to learn more about the BMPs: http://www.cluin.org/greenremediation

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Office of Solid Waste and Emergency Response (5102G)

EPA 542-F-12-028
September 2012

Green Remediation Best Management Practices: Mining Sites

Office of Superfund Remediation and Technology Innovation

Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outline the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) recommended in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.

Federal agencies estimate that approximately 500,000 abandoned mines and associated ore processing facilities exist across the United States.[2] Of these, approximately 130 National Priorities List (NPL) or NPL-caliber sites covering more than a million acres are contaminated from past hard rock mining activities and are now undergoing cleanup led by the lead federal agencies or potentially responsible parties. Much of the work to remediate and reclaim abandoned mine land (AML) at other sites is conducted or overseen by state agencies, often with voluntary assistance from non-profit groups.

Cleanup and restoration of sites with areas formerly used to mine coal or hard rock ore (containing metals such as gold or copper or other resources such as phosphorous) present unique challenges. Past activities typically included onsite extraction, crushing, and separation of extracted mineral ore into useable material (beneficiation) and onsite or offsite processes such as smelting. Environmental contamination and degradation at mining sites commonly resulted from:

- Waste rock and beneficiation waste such as mill tailing piles often scattered in numerous surface impoundments
- Mining influenced water (MIW), including contaminated surface water, groundwater, and seepage from former mine adits (openings)
- Waste in the form of slurry that was injected into abandoned coal mines
- Waste sludge (often containing surfactants and flocculants) that was discharged into unlined lagoons, or
- Aerial deposition of heavy metals and other contaminants from ore processing activities.

Steps to remediate these conditions can pose their own environmental footprint, which can be reduced by adhering to EPA's ***Principles for Greener Cleanups***. The core elements of a greener cleanup involve:

- Reducing total energy use and increasing the percentage of renewable energy
- Reducing air pollutants and greenhouse gas (GHG) emissions
- Reducing water use and negative impacts on water resources
- Improving materials management and waste reduction efforts, and
- Protecting ecosystem services.

EPA's suite of **green remediation BMPs** describes specific techniques or tools to address the core elements.

The availability of liquid fuels and electric power, for example, poses a major challenge at many mining sites due to their remote and often high-altitude locations. Green remediation BMPs focusing on fuel and energy conservation techniques or renewable sources of energy can help minimize the environmental footprint of particular activities (and improve the project's environmental outcome) while addressing this challenge. Three documents in EPA's "BMP fact sheet" series[3] provide detail about BMPs relating to fuel or energy use or optimization of energy-intensive ex situ technologies often deployed in MIW treatment plants:

- *Green Remediation Best Management Practices: Clean Fuel & Emission Technologies for Cleanup*[3a]
- *Green Remediation Best Management Practices: Integrating Renewable Energy into Site Cleanup,*[3b] and
- *Green Remediation Best Management Practices: Pump & Treat Technologies.*[3c]

Other significant opportunities to reduce the environmental footprint correspond with common components of mining site cleanup projects:

- ***Characterizing MIW*** in order to better understand the nature and extent of contamination
- ***Using passive treatment systems*** for acid mine drainage
- ***Integrating onsite renewable energy*** to power cleanup operations
- ***Installing soil covers*** to stabilize soil and waste piles and reduce their exposure
- ***Reclaiming residual natural resources*** such as economically valuable metals from waste piles, and
- ***Integrating cleanup with restoration and reuse*** of sites.

Characterizing MIW

Green remediation BMPs for MIW characterization prior to remedial system design and construction include:

- Use field test kits for screening whenever possible, to reduce the number of samples requiring offsite laboratory analysis
- Deploy low-flow sampling equipment whenever possible, to minimize purge volumes and energy use while producing little investigation-derived waste
- Deploy remote sensing techniques for identifying and surgically removing any subsurface obstructions or potentially dangerous materials (such as residual explosives), to avoid excavating excess soil or material
- Use noninvasive, less energy-intensive investigative techniques such as borehole and surface geophysical methods for identifying fracture zones and groundwater flow/direction, to optimize contaminant mapping, well placement, and treatment system design
- Maximize reuse of existing boreholes for capturing and hydraulically controlling seeps, to avoid additional land and subsurface disruption caused by creation of new boreholes
- Choose sonic instead of conventional rotary drilling or hammer techniques whenever possible, to minimize discharged waste, avoid the need for drilling fluid, and reduce noise
- Use phosphate-free detergents instead of organic solvents or acids to decontaminate sampling equipment, and dispose of used washwater in contained vessels or designated onsite areas, and
- Use environmentally friendly drilling fluid or water in a closed-loop system when rotary drilling is needed.[4]

Additional BMPs are described in *Green Remediation Best Management Practices: Site Investigation*.[3d]

Voluntary cleanup by a non-profit environmental group at the ***DeSale Restoration Area*** *in western Pennsylvania involves a* ***passive treatment system*** *for acid mine drainage exiting abandoned surface and underground coal mines. The system contains agricultural waste (spent mushroom compost) and limestone from a nearby quarry. It effectively neutralizes about 180 pounds of acidity per day. Over eight years of operation, the system recovered about two tons of manganese oxide; proceeds from sale of the recovered material were used to maintain the treatment system and construct additional systems in other portions of the Slippery Rock Watershed.*[5]

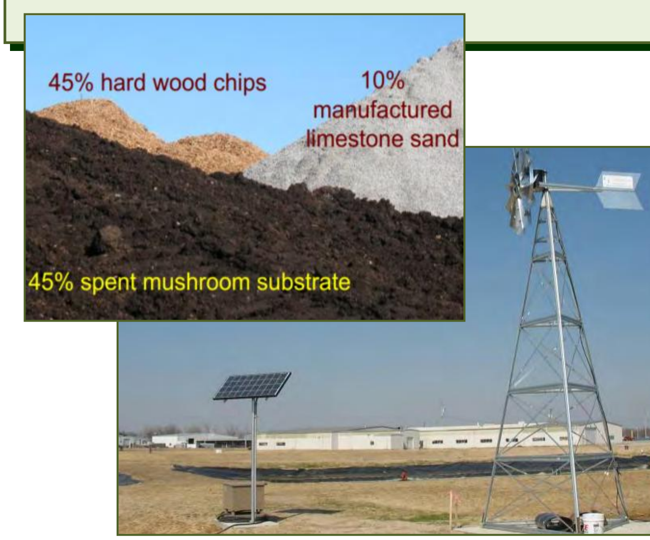
Using Passive Treatment Systems

Highly acidic water rich in metals (acid mine drainage [AMD]) can be produced indefinitely after mining activities cease and continue to pose significant risks to aquatic life and to humans through fish or water consumption or direct contact. AMD and other MIW could be remediated by a passive treatment system comprising one or more ground-surface "cells" that take advantage of a site's naturally occurring chemical and biological processes. For example, a passive treatment system could consist of an oxidation pond, a biochemical reactor to transform contaminants into immobile forms and increase pH, and remediation polishing technologies such as aerobic wetlands or limestone beds. The site's natural hydraulic gradients or a pumping system can be used to transport the MIW to these treatment cells from adits or seeps. A passive treatment system also can be used as a polishing step following ex situ treatment of MIW in an onsite water treatment plant.

Through EPA funding, the University of Oklahoma constructed a passive treatment system for seepage from abandoned underground lead and zinc mines at the ***Tar Creek Superfund Site*** *in Oklahoma. The system encompassed oxidation/re-aeration ponds, surface flow wetlands, vertical-flow/sulfate-reducing biochemical reactors, and horizontal flow limestone beds. Approximately 90% of each biochemical reactor consisted of* ***agricultural and forestry waste products****.*

To accelerate oxidation in the ponds, ***off-grid renewable energy systems*** *were integrated into the system's design:*

- *A 20-foot windmill provides mechanical energy to power a vertical displacement pump operating in one pond, and*
- *A photovoltaic array generates electricity to directly operate a compressor in an adjacent pond.*



Green remediation BMPs for constructing a passive treatment system include:

- Design extensive stormwater controls prior to use of heavy machinery, to avoid additional runoff and watershed sedimentation or contamination; controls may involve existing rock-lined channels or other topographic features as well as engineered structures such as berms and grassy swales
- Maximize reuse of remnant service roads or cleared areas, and use surgical techniques to remove any vegetation during construction of new transportation corridors or work areas

- Explore the use of check dams and other structures to capture any rainwater or snow melt for application in onsite activities such as controlling excavation dust, rinsing hand-held equipment after field use, or irrigating newly planted vegetation
- Preserve existing corridors or create new ones if needed to assure safe passage of migratory animals, and
- Schedule startup of major land-disturbing activities during non-nesting or non-birthing periods of local ground-dwelling birds or wildlife, and install grates in mine adits to allow bat passage.

A biochemical reactor is typically lined and contains organic-rich material along with buffering material such as crushed limestone. Lumber, agricultural, or greenhouse byproducts (such as hardwood chips, mulch, hay, livestock manure, or spent mushroom compost) or municipal biosolids often provide the organic matter. BMPs for constructing and monitoring a biochemical reactor within a passive treatment system include:

- Choose a geomembrane (liner) manufactured through processes involving a low environmental impact, such as those described in ISO 14001 (Environmental Management Systems)
- Procure organic materials from producers closest to the site, to minimize fuel consumption and related air emissions from heavy trucks
- Explore other industrial byproducts that may be more available on a local basis, such as chitin or cocoa shells
- Consider use of novel protein-containing food waste such as banana peels to bind metals existing at trace concentrations in water; research has shown that such waste may improve metal detection during monitoring and potentially serve as a sorbent to remove metals at higher concentrations,[6] and
- Install remote monitoring equipment such as sonde units to continuously collect water quality data while significantly reducing frequency of site visits.

Integrating Onsite Renewable Energy

As an alternative to using and transporting liquid fuel or attempting to extend connection to the local utility grid, onsite renewable energy systems may be installed during remedy construction or added as needed during system operation to:

- Supplement gradient-driven transfer of MIW to or among treatment cells
- Improve treatment efficacy of certain cells such as those used for aeration, and
- Generate electricity or mechanical energy for routine field equipment or small devices.

Mobile units now available in the commercial market offer significant potential for generating renewable energy at remote locations such as mining sites. Depending on a site's accessibility and terrain, mobile systems could provide collapsible photovoltaic (PV) arrays or small wind turbines mounted on trailers designed to supply over 20 kilowatts (kW) of electricity. Smaller arrays or mini turbines (generating less than 1 kW) can be packaged on simple frames or skids to be hauled by a pick-up truck or all-terrain vehicle.

In addition, surface waters on or adjacent to many mining sites offer the potential of hydropower at various scales. A 2 kW micro-hydropower submersible turbine, for example, can be deployed to operate with a hydraulic head as little as 1.5 meters to provide mechanical energy or drive an electricity generator. In contrast, a 36 kW microturbine at the Summitville Mine in Del Norte, Colorado, generates hydropower that offsets grid electricity consumed by an onsite water treatment plant.

***Solar energy** is used at the **Leviathan Mine** Superfund site in the Sierra Nevada Mountains of California for four remote monitoring stations at key seeps and creeks and for an onsite emergency shower unit. Each monitoring station was custom built by EPA Region 9 staff to include a PV array for battery charging; multiprobe sonde to measure water quality parameters of streams impacted by AMD; and satellite telemetry for hourly data collection and transmission to EPA offices.*

The Atlantic Richfield Company operates a PV-powered meteorological station and a solar thermal unit at adjacent portions of the site. The solar thermal unit maintains warmth throughout the year for an electrical system used to control propane-fueled generators powering a semi-passive treatment system. In cooperation with the National Renewable Energy Laboratory, EPA Region 9 is investigating larger renewable energy applications to power the treatment system pumps, which currently rely on summer-only fuel delivery to this remote site.

Installing Soil Covers

Waste rock and ore process tailings found in surface impoundments at mining sites typically settle over time. Impoundment stabilization often involves constructing one or more soil covers (caps) for waste left in place or consolidated in one or more selected areas. Green remediation BMPs for designing a cover include:

- Mimic rather than alter the site's natural setting, to improve the cover's long-term performance and protect local ecosystem services
- Account for potential effects of climate change, such as increased vulnerability to flooding or sudden shifts in temperature

- Explore industrial waste products as a partial substitute for productive soil to be imported for a cover's compacted clay layer or the liner of a new landfill for waste consolidation, if product testing shows no contaminant leaching, and
- Consider anticipated site reuse options during design of a cover; for example, industrial redevelopment of the site may reduce the volumes of materials to be imported for a vegetative cover.

Biosolids, limestone, potash, and fly ash were blended to form a ***soil amendment*** *that was spread on ground surfaces through a single pass at the* ***Palmerton Zinc Pile*** *Superfund site in Carbon County, Pennsylvania. A seed mix of native plants unlikely to accumulate metals (such as big and little bluestem, deertongue, Indiangrass, and switchgrass) was applied with the ground amendment and aerially distributed.*

Onsite studies conducted 10 years later indicated significant re-growth of vegetation in formerly denuded areas across the estimated 2,500 acres previously amended and little accumulation of metals such as cadmium, lead, and zinc in resident mammals.[7] Current efforts by EPA, the Pennsylvania Game Commission, and the National Park Service focus on developing a remediation and reuse plan for remaining denuded public land covering about 1,200 acres along the Appalachian Trail.

Soil covers at some mining sites involve use of an evapotranspiration (ET) system, which relies on a thick layer of soil with vegetative cover capable of storing water until it is transpired or evaporated (and consequently minimizing percolation into underlying waste). Soil in the upper layer is often amended to restore quality of the soil and provide nutrition to the vegetation. Amendments containing organic-rich material such as biosolids can also bind metal in soil, thereby reducing the metal bioavailability. Green remediation BMPs for an ET cover include:

- Select drought-resistant plants for the upper vegetative layer, to reduce maintenance needs; in some cases, non-native species may offer higher viability potential and water storage capacity than native plants
- Preserve biodiversity and related ecosystem services by installing a suitable mix of non-invasive grasses, forbs, and shrubs
- Choose nonsynthetic nutritional soil amendments such as compost instead of chemical fertilizers
- Consider onsite generation of compost made of forest waste resulting from logging activities or disease-infested trees, to reduce import of soil amendments; for example, "beetle kill" trees could provide a significant source of biomass
- Explore use of biochar (a charcoal-like substance produced by heating biomasss in the absence of oxygen) as a soil amendment, to better retain moisture and nutrients, and
- Blend amendments into a single mixture that can be applied above the cover through a one-step process rather than a series of applications, to minimize operation of front loaders and other heavy machinery.

Additional BMPs regarding ET or other alternative designs as well as conventional covers are described in *Green Remediation Best Management Practices: Landfill Cover Systems & Energy Production*.[3e]

Research is underway in test plots at the ***Hope Mine*** *near Aspen, Colorado, to evaluate efficacy of* ***biochar amendment*** *in restoring soil affected by mine waste rock piles. Along with biochar, the applied amendment contained a seed mix, compost, hydromulch, and naturally occurring mycorrhizal fungi to help plant roots take in nutrients. In each plot, biodegradable netting was placed on ground surfaces to hold the amendment in place. No irrigation was needed for plant re-establishment, which occurred within one year.*

Reclaiming Residual Natural Resources

Historic landfills, waste piles, and components of passive treatment systems at many mining sites offer the opportunity to reclaim rather than dispose of valuable metals or other natural resources. The reclaimed material often can be sold to industrial businesses for recycling. Depending on the type of materials formerly mined onsite, green remediation BMPs include:

- Use water treatment systems that recover metals from AMD; for example, a system at the French Gulch site near Breckenridge, Colorado, produces zinc sludge that is used directly by a nearby zinc smelter
- Recover metals such as copper or nickel from oxides settling in limestone beds
- Recover gold or copper from former mine tailings, if control of associated cyanide- or sulfuric acid-containing solution or leachate is feasible
- Recover metals such as copper in slag remaining from past smelting

- Explore options for excavating and recycling landfill wastes from past coal mining and processing into synthetic fuel (synfuel) that can be converted to useable energy, rather than installing a new cover system, and
- Explore potential to use methane from a co-located landfill, ongoing coal extraction processes, or an abandoned coal mine with methane recovery potential;[8] at the abandoned Cambria Slope 33 Mine in Pennsylvania, for example, recovered waste methane powers a 0.7 megawatt (MW) off-grid electricity generation facility for onsite natural gas extraction.

*During cleanup at the 97-acre **Fairmont Coke Works-Sharon Steel Site** in West Virginia, reclamation of historic landfill material for use as **synfuel feedstock** resulted in:*

- *Reduced burdens on the hazardous waste-permitted facility otherwise receiving nearly 241,000 tons of waste*
- *Avoided GHG emissions and heavy road use associated with transport of waste to the permitted facility*
- *Substitution of raw coal otherwise mined and processed to produce electricity for about 37,000 homes over one year*
- *Averted use of water otherwise needed to produce an equivalent amount of fuel from raw coal by an offsite coal processing plant.*

Re-establishment of vegetative and soil conditions that existed before mining activities occurred often is a critical cleanup step and accelerates site restoration and productive reuse. Re-established vegetation can help:

- Stop physical dispersal of the waste through erosion, wind, or human or animal direct contact
- Minimize infiltration to and through mass below a landfill/waste cover and control associated leachate production and release
- Provide elements of an ET cover that could develop naturally over time
- Apply phytotechnologies to treat soil or water contaminated by non-heavy metals or chemical compounds used in past processing activities
- Capture and sequester atmospheric carbon, and
- Restore ecological services to the community.

***Ecosystem services** are the benefits that people, communities, and economies receive from nature. At mining sites, healthy soil and vegetation provide significant ecosystem services such as:*

- *Purifying shallow groundwater and surface waters*
- *Retaining water otherwise lost to runoff or evaporation, and*
- *Controlling erosion and minimizing associated loss of valuable topsoil during flooding.*

*EPA's National Risk Management Research Laboratory recommends a **three-step process to select plants** most effective for a vegetative landfill cover and complementary to site reuse plans:*

1) *Obtain lists of suitable plants from:*
   - *The pertinent state highway department*
   - *Relevant and concerned non-government organizations such as the Nature Conservancy*
   - *Researchers or contractors knowledgeable about the role of vegetation in remediation and the site's conditions*
2) *Cross-reference the lists to identify plants recommended by multiple organizations or experts*
3) *Consult with the local U.S. Department of Agriculture or U.S. Forest Service office to determine which of those plants are likely most viable in the target microclimate.*

Integrating Cleanup with Restoration/Reuse

Green remediation BMPs can be implemented during cleanup design or construction phases to ultimately help restore mining-impacted ecological systems; for example:

- Install trees that complement forestry plans on adjacent properties owned by government agencies such as the U.S. Forest Service, if the installation area excludes constructed soil covers and suggests tree survival under likely acidic conditions
- Promote surface water corridors that replicate original riparian conditions and complement regional watershed plans
- Incorporate re-use preferences of organizations wishing to expand local recreational or environmental education services for the community
- Design cleanup infrastructures that complement municipal or industrial plans to use the land for regional waste-to-energy facilities; for example, timber and agricultural businesses could supply biomass for electricity generation, or food producers/retailers could provide waste serving as feedstock for a biodigester (which converts waste heat to useable energy), and
- Coordinate with prospective renewable energy developers to combine cleanup efforts with site reuse for producing energy from onsite renewable resources; EPA's RE-Powering America's Land initiative can provide assistance in pursuing renewable energy development.[9]

- *At the **Chevron Questa Mine** site in Taos County, New Mexico, a 1 MW concentrated solar photovoltaic (CPV) facility currently operates above 20 acres of covered mine tailings as remediation work in other areas begins; since early 2011 startup, the facility has sold generated electricity to a local utility under a power purchase agreement.*
- *At the **New Rifle Mill** site in Colorado, portions of the site were converted to an energy innovation center without disturbing continued cleanup efforts to address uranium and vanadium contamination; the first installation of clean energy technology on this site is a 12-acre, 1.7 MW zero-emission solar energy system that powers a co-located regional wastewater reclamation facility.*

Remedy construction and operation as well as site restoration at the ***Elizabeth Mine*** *Superfund site near South Stratford, Vermont, involves a* ***range of BMPs*** *to: reduce air contaminants associated with onsite or offsite fuel consumption; use onsite rather than imported natural resources wherever possible; establish processes for maximum recycling or reuse of waste materials; and initiate a procurement process for environmentally preferred products. The greener cleanup strategy includes methods for preserving the site's historic aspects and ecosystem services.*[10]

Mining Sites: Recommended Checklist

Characterizing MIW

- ✓ Use field test kits, remote sensing techniques, and geophysical methods wherever possible
- ✓ Deploy low-flow sampling devices
- ✓ Choose sonic drilling techniques and environmentally friendly drilling fluids wherever possible

Using Passive Treatment Systems

- ✓ Choose quickly renewable agricultural products or industrial byproducts rather than raw natural resources as organic-rich materials wherever possible
- ✓ Integrate stormwater controls and capture rainwater and snowmelt for onsite use
- ✓ Minimize site disturbance by reusing remnant roads and other infrastructure components

Integrating Onsite Renewable Energy

- ✓ Maximize use of renewable energy systems to power cleanup equipment
- ✓ Deploy mobile units to generate power from solar or wind resources as needed

Installing Soil Covers

- ✓ Design with the intent of maintaining natural settings and addressing potential effects of climate change
- ✓ Maximize control of soil erosion caused by rain, wind, or construction activities
- ✓ Explore use of industrial waste products rather than imported soil

Reclaiming Residual Natural Resources

- ✓ Reclaim valuable metals from tailings or leachate
- ✓ Explore production of useable energy from onsite waste left by coal extraction/processing
- ✓ Investigate potential to convert methane from a co-located landfill into useable energy

Integrating Cleanup with Restoration/Reuse

- ✓ Complement regional forestry and watershed plans
- ✓ Deign cleanup infrastructures that complement reuse options such as recreation
- ✓ Coordinate with prospective utility-scale renewable energy developers

Since 2001, a ***public-private partnership*** *among the Pennsylvania Department of Environmental Protection, Trout Unlimited, other government agencies, local stakeholders, and private industry has worked to address coal AMD at the abandoned* ***Fran Contracting, Inc. Camp Run No. 2*** *surface mine near Renovo, Pennsylvania. Preliminary remediation work included constructing a pilot-scale passive treatment system to treat AMD affecting three Susquehanna River tributaries with high or exceptional values for water quality and cold-water fisheries.*

The system's sulfate-reducing bioreactor consisted of 50% wood chips, 30% limestone, 10% manure, and 10% hay in a lined cell three feet below ground surface and capped with soil. Performance monitoring indicated the bioreactor achieved significant increases in pH and reductions in acidity and iron, aluminum, and sulfate concentrations within one year of startup. Costs to construct the system, which treated about one gallon of AMD per minute, totaled $42,000.

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- e *Landfill Cover Systems & Energy Production*; EPA 542-F-11-024; December 2011

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9 U.S. EPA; RE-Powering America's Land; http://www.epa.gov/oswercpa/index.htm

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EPA/OSWER appreciates the many contributions to this fact sheet, as provided by EPA's National Mining Team, regional offices, and laboratories or by private industry.

The Agency is publishing this fact sheet as a means of disseminating information regarding the BMPs of green remediation; mention of specific products or vendors does not constitute EPA endorsement.

Visit **Green Remediation Focus** online:
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Office of Solid Waste and Emergency Response (5203P)

EPA 542-F-12-029
October 2012

Green Remediation Best Management Practices:
Implementing In Situ Thermal Technologies

Office of Superfund Remediation and Technology Innovation — Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outline the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) recommended in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.

Over recent years, the use of in situ thermal (IST) systems to remediate contaminated sites has notably increased. Since fiscal year 2005, for example, remedies involving IST technology have been selected for 18 Superfund sites. IST technologies also have been used more frequently for RCRA corrective actions, brownfield sites, or military installations needing accelerated cleanup. When properly applied in well-defined contaminant source zones, IST technologies may effectively remediate a site within months rather than years.

IST implementation typically involves independent or combined use of three primary technologies to apply heat in targeted subsurface zones: electrical resistance heating (ERH), thermal conductive heating (TCH), and/or steam enhanced extraction (SEE). IST implementation also relies on soil vapor extraction (SVE) to collect and carry the chemical vapors to the surface for treatment. Other remediation system components that may be used in conjunction with IST technologies include pumping networks to control groundwater flow in the treatment zone and dual-phase extraction wells to extract source water, non-aqueous phase liquid (NAPL), and vapor. By aggressively treating the source area, IST implementation can significantly reduce the amount of contamination needing to be addressed by groundwater cleanup efforts.

IST technologies can be used to:

- Treat contaminant source areas in diverse geologic strata, including clay, silt, sand, and fractured bedrock
- Remove volatile organic compounds (VOCs) and semivolatile organic compounds sorbed to the soil in both the saturated and unsaturated (vadose) zones of the subsurface
- Capture and treat contaminants existing in the non-aqueous phase, or
- Strip dissolved contaminants from groundwater.

The environmental footprint of implementing these technologies can be reduced by adhering to EPA's ***Principles for Greener Cleanups***. The core elements of a greener cleanup involve:

- Reducing total energy use and increasing the percentage of renewable energy
- Reducing air pollutants and greenhouse gas (GHG) emissions
- Reducing water use and negative impacts on water resources
- Improving materials management and waste reduction efforts, and
- Protecting ecosystem services.

EPA's suite of **green remediation BMPs** describes specific techniques or tools to achieve a greener cleanup. Associated documents in EPA's "BMP fact sheet" series provide detail about BMPs applying to various remediation technologies, cleanup phases, or common issues.[2] The BMPs are intended for general use or adaptation wherever feasible; for example, BMP modifications may be necessary to account for the relatively short duration of most IST applications.

Opportunities to reduce the environmental footprint of IST applications correlate to the common cleanup phases:

- ***Design***, including ERH, TCH, and SEE components as well as vapor extraction systems
- ***Construction***
- ***Operation and maintenance***, and
- ***Monitoring***.

Design

Green remediation strategies for designing an IST system depend on a thorough understanding of the site hydrogeology and contaminant location(s) to assure that:

- The target zone, including the majority of source-area NAPL, receives treatment
- System modifications such as reduced heating rates or duration can be made for selected areas during project design or as treatment progresses, and
- Areas outside the target zone are not heated.

This assurance helps allocate resources effectively and avoid unnecessary expenditure of water, energy, and other natural resources. It also helps minimize emission of air contaminants, generation of additional waste, and disturbance to land and existing ecosystems throughout the life of the project. Green remediation BMPs particularly applying to IST system design include:

- Test and refine the conceptual site model previously developed during site investigation, and prepare for additional refinements during system construction and operation
- Conduct comprehensive soil sampling to assure that data used for determining baseline electrical resistivity represent the entire treatment area; for example, wetter soil areas may need lower power inputs than dryer areas in order to propagate an electricity current and meet target temperatures
- Maximize use of waterless direct-push drilling tools for screening purposes, such as a membrane interface probe for VOCs or a laser-induced fluorescence probe for petroleum hydrocarbons, rather than more invasive and energy-intensive rotary drilling techniques needed for confirmatory sampling, and
- Use other high-resolution imagery techniques such as seismic reflection to confirm stratigraphic continuities.[3]

Additional BMPs are described in *Green Remediation Best Management Practices: Site Investigation*.[2a]

Effective IST system design also relies on analytical models to optimize the spacing of heating wells in relation to energy use and heating duration and the efficiency of vapor recovery equipment. Modeling efforts may be aided by applying EPA's *Methodology for Understanding and Reducing a Project's Environmental Footprint,* which provides an approach to quantifying a project's energy, air, water, materials, and waste components.[4]

EPA's footprint assessment "methodology" was used for designing IST implementation and excavation with offsite disposal to remediate the ***South Tacoma Channel Well 12A*** *site in Washington. Although IST technology is energy intensive, its estimated environmental footprint was found to be lower at this site when compared to excavation. The lower footprint was attributed to the site's available electricity, which is supplied by offsite facilities where more than 98% of the power is generated from hydroelectric and nuclear resources.*

Based on the footprint assessment results, remedial designs were modified to reflect smaller excavation areas (involving an approximate 50% reduction in the excavation volume) and a corresponding, larger IST target zone. BMPs used to reduce the footprint of the remaining excavation/disposal efforts and construction of the IST system included:

- *Using cleaner engines, cleaner fuel, and diesel emission control technology on all diesel equipment*
- *Segregating and locally recycling excavated concrete, and*
- *Selecting the nearest soil "borrow" sources and waste disposal facilities, to minimize transport and associated air emissions.*

Green remediation BMPs for general design of IST systems include:

- Minimize piping runs from the extraction well field to the treatment system
- Explore combined thermal treatment technologies at sites with varying geologic units, to maximize efficiencies
- Consider a phased approach that sequentially heats subareas of large sites, to reduce equipment needs and identify opportunities for conserving energy and other resources over time
- Integrate sources of renewable energy at various scales, such as small re-useable or portable photovoltaic systems or wind turbines to provide supplemental power for equipment such as pumps or blowers, and/or utility-scale systems that may be used for ongoing or future site activities or for sale as distributed power,[2b] and
- Establish a project baseline on information such as electricity and water consumption, volumes of material purchases, and offsite disposal volumes, which can be used to identify, implement, and measure continuous improvements to an operating system and identify opportunities for modifications resulting in major efficiency gains.

Sources of ***renewable energy*** *may include:*

- *Solar energy captured by photovoltaic, solar thermal, or concentrated solar power technology*
- *Wind energy gathered by mechanical windmills or electricity-generating turbines*
- *Biomass such as forestry or agricultural waste*
- *Methane recovered from landfill gas, and*
- *Hydropower from flowing surface water or ocean waves.*

Most green remediation BMPs for IST implementation apply to ERH, TCH, and SEE technologies, although different processes and equipment involved in each can provide unique opportunities to reduce their environmental footprint.

Electrical Resistance Heating

ERH technology involves subsurface placement of electrodes that can accept three- or six-phase electrical current. Resistance to the current's passage among the electrodes causes heating of soil across the entire treatment area or at selected subsurface intervals. To facilitate soil contact with the electrode, graphite or steel shot is placed around each electrode. Target temperatures are generally 100 °C or the boiling point of water, which may be higher at increased depths below the water table. Loss of heat at ground surfaces is minimized by installing a cap.

The contaminants are steam stripped or vaporized and the steam/vapor is collected by vacuum vapor recovery wells for treatment at the ground surface. At some sites, the recovery wells can be constructed as dual-phase (liquid and vapor) recovery wells. As the water boils off near electrodes in the vadose zone, additional water is added to maintain soil electrical conductance, usually through use of a drip tube system. The subsurface heating process is monitored by thermocouples and pressure transducers.

The ex situ vapor treatment system typically includes piping, one or more blowers, a knockout tank to separate vapor from entrained water, a condenser for pre-treatment cooling, and treatment equipment such as granulated charcoal or thermal oxidation units. If groundwater and/or NAPL is extracted, additional equipment such as a separator tank with a water-treatment system is required.

Green remediation BMPs for ERH system design include:

- Consider co-locating electrodes and recovery wells in the same borehole, particularly in the saturated zone, to minimize land disturbance
- Assure all electrodes are free of rust or debris before placement, to maximize heat transfer
- Use condensate or treated water as makeup water for the condenser cooling tower or recycle them into the drip system, and
- Use off-gases from a thermal oxidation unit to help heat recycled water for the drip system.

In 2007, an ERH system was installed at the ***Total Petrochemicals & Refining USA Inc.*** *former bulk fuel terminal in Greensboro, North Carolina. This IST application:*

- *Used high resolution techniques and analytical modeling to divide the site into four 1.2-acre zones and develop a phased heating approach that optimized use of electricity and natural gas*
- *Used a real-time control system that allowed discrete targeting of specific subsurface depth intervals for heating on a minute-by-minute basis to increase heating efficiency*
- *Reused treated water to maintain moisture at electrodes*
- *Used an air-water heat exchanger that allowed the thermal oxidizer off-gas to serve as a source of heat for pre-heating water prior to its reuse at the electrodes*
- *Included frequent process review and optimization to focus the use of power and other resources on hotspots, and*
- *Repurposed the recovered/recondensed waste product (gasoline) through sale to local fuel recyclers.*

By the end of active heating in the fourth (final) zone in 2012, approximately 880,000 pounds of contaminant mass (approximately 75% of the original mass estimate) had been recovered. A total of 10.4 MW/hr of electricity was used to operate the ERH system, at a cost of $1.8 million. The overall unit cost for this IST remedy was $90-95 per cubic yard.

2007 Groundwater Remediation Award
National Ground Water Association

Thermal Conductive Heating

Thermal conductive heating (also known as in situ thermal desorption) supplies heat to the soil through steel wells that contain heaters reaching to various depths. In areas of shallow groundwater, TCH implementation may involve horizontal in addition to vertical wells for vapor extraction in order to minimize upwelling caused by vacuum extraction. BMPs for TCH design include:

- Assure suitable sizing of in-well heating units, to optimize energy use
- Include feedback loops in the process control system, to allow precise application of heat and the desired temperature and duration
- Explore the use of natural gas-fired systems that enable in-well combustion of the contaminants and recovery of associated heat, resulting in a lower energy demand
- Integrate a combined heat and power (CHP) system powered by natural gas or cleaner diesel, to generate electricity while capturing waste heat that can be used to condition air inside buildings used for vapor treatment or other onsite operations, and
- Choose designs that allow post-cleanup reuse of the underground piping network for infrastructure components such as geothermal systems.

Steam Enhanced Extraction

SEE technology involves introduction of steam to the subsurface by injecting it from ground surface into wells. The resulting condensate and excess steam are extracted for above-ground treatment through conventional water and vapor treatment systems. Green remediation BMPs unique to SEE technology include:

- Choose a water-tube boiler rather than a fire-tube boiler wherever feasible; the smaller tubes in water-tube boilers increase boiler efficiency by allowing more heat transfer from exhaust gases
- Consider adding pipe insulation to prevent heat loss and increasing insulation wherever feasible for other components most susceptible to heat loss
- Install heat recovery equipment such as feedwater economizers and/or combustion air preheaters, to recover and use heat otherwise lost in exhaust gas
- Minimize excess air in the steam generation process, to reduce the amount of heat lost through the stack, and
- Install solar thermal equipment to preheat boiler feed-water and makeup water, to reduce the energy needed for raising water temperatures to the target levels.

More information about opportunities to improve steam system performance and tools to assess steam systems is available from the U.S. Department of Energy.[5]

SEE System Optimization: Rules of Thumb

Small changes in boiler efficiency can result in significant fuel conservation and related cost savings. For example:

- *A typical natural-gas fired 120,000 pounds/hour industrial boiler producing 700 °F steam at a pressure of 400 psig could cost $13 million to operate over one year;[7] a boiler efficiency improvement as small as 1% could reduce the operating cost by $130,000.*
- *Boiler efficiency can be increased by 1% for each 15% reduction in excess air or 4 °F reduction in stack gas temperature.[6]*
- *Minimizing the non-condensable matter in blowdown from condensing equipment for boiler systems is critical; every 1% of non-condensables in steam can cause a 10% reduction in the heat transfer coefficient.[7]*

*Cleanup of Operable Unit 2 at the **Groveland Wells Superfund Site** in Groveland, Massachusetts, in 2010-2011 involved ERH technology with enhanced in situ steam production to address a trichloroethene (TCE) source area. Implementation included:*

- *Subsurface injection of water-conditioning salts to increase electrical conductivity of the soil*
- *Installation of a sound-absorbing curtain to reduce transmission of high frequency sounds emitted by the vapor extraction system blowers*
- *Use of a steam generator to operate 14 steam "spears" that increased moisture content and electrical conductivity in targeted portions of the shallow vadose zone, and*
- *Installation of two 2-inch-thick polystyrene insulating boards directly above the concrete vapor cover, to reduce heat loss by approximately 98% during unexpected winter operations.*

Electricity costs for the six-month ERH application, steam enhancement, and extraction systems totaled approximately $604,000. Upon system shutdown, performance data indicated removal of over 1,300 pounds of VOCs and a 97% reduction in source area TCE concentrations.

Soil Vapor Extraction

The environmental footprint of systems used for ex situ treatment of vapors extracted from IST systems is affected significantly by generation of material waste and wastewater as well as consumption of energy. Roughly 70% of SVE systems at Superfund sites have used granular activated carbon (GAC) treatment and approximately 25% used thermal or catalytic oxidation. Wastes potentially needing offsite treatment and disposal include spent non-regenerable carbon canisters or liquid condensate from air/water separators. Green remediation BMPs for designing vapor extraction systems include:

- Use the minimum air flow rate that can meet the cleanup objectives and schedule while minimizing energy consumption
- Assure suitable sizing of vacuum pumps and blowers that are used to extract air from the subsurface, which will optimize energy use
- Consider using combined cryogenic compression and condensation technology instead of thermal oxidation to treat vapor streams with high contaminant concentrations; a cryogenic system allows recovery of contaminant vapor as a liquid for potential recycling or resale
- Treat condensate in onsite systems where contaminant types and concentrations permit, rather than discharging it to (and increasing the burden on) the publically owned treatment works (POTW)
- Plan to recycle condenser water as supplemental cooling water where concentrations permit, to minimize use of fresh water
- Minimize sizing of above-ground structures that house extraction or treatment equipment and use green building elements such as passive lighting, rainwater collection systems, and federally designated green products,[8] and
- Consider including horizontal wells in the well network, to improve overall efficiency of air extraction.

Additional BMPs regarding vapor extraction system design are available in *Green Remediation Best Management Practices: Soil Vapor Extraction & Air Sparing.*[2c]

*Since late 2009, a cryogenic compression and condensation process has been used to recover hydrocarbons from SVE operations at the **State Road 114** Superfund site in Levelland, Texas. Over the first seven months of operation, the process brought in project revenue of approximately $45,000, approximately 70% of the SVE system's electricity costs.*

Construction

Well installation can significantly contribute to the environmental footprint of IST system construction. Green remediation BMPs that can help reduce the environmental footprint of construction activities relating to wells and other IST system components include:

- Use direct-push technology (DPT) for well installation wherever feasible, to eliminate drill cuttings and associated waste disposal, avoid consumption or disposal of drilling fluids, and reduce drilling duration by as much as 50-60% when compared to conventional rigs; for example, DPT can be used to install standard 2-inch diameter vacuum extraction wells, air injection wells, groundwater depression wells, and monitoring points
- Segregate drill cuttings by appropriately stockpiling next to a borehole and awaiting analytical results; under many cleanup programs, clean soil may be distributed near boreholes or backfilled into a boring
- Choose ground surface capping materials containing recycled contents[9]
- Install a thermal insulation vapor cover to maximize IST operations in cold climates, and
- Winterize all above-ground piping before onset of freezing temperatures, to avoid downtime and inefficiencies associated with freezing temperatures.

Evaluating the options may include consideration of potential environmental tradeoffs. In the case of using DPT, for example, its deployment ease can reduce fuel-intensive field activities; however, attempted DPT use at depths approaching the technology's typical limit (100 feet) could result in wasted fuel or well installation failure.

Another example is the use of small-diameter injection wells that can lead to large pressure drops and increased energy consumption of the system.

Emission of GHG and particulate matter from trucks and other mobile sources during IST construction can be reduced through BMPs such as:

- Retrofit equipment for cleaner engine exhaust
- Use ultra low-sulfur diesel in heavy machinery, and
- Institute a reduced idling plan.

Additional BMPs regarding fuel conservation and reduced air emissions from stationary as well as mobile sources are provided in *Green Remediation Best Management Practices: Clean Fuel & Emission Technologies for Cleanup.*[2d]

Other BMPs that can be used during IST system construction involve minimizing disturbance to the land, ecosystems, and nearby residents or workers.

- Include sound-proofing material in aboveground housing for vapor extraction equipment that often generates high levels of noise; acoustic barriers with recycled or recyclable components may be constructed onsite or obtained commercially
- Choose centrifugal blowers rather than positive displacement blowers (which tend to generate more noise) if the applied efficiencies are comparable
- Install air-line mufflers to decrease equipment noise
- Install directional shields on significant lighting sources such as safety beacons for the power distribution system, to minimize visual disturbance of nearby human or animal populations
- Limit tree removal to only those truly obstructing construction or operation of the treatment systems, and
- Transplant any shrubs from proposed extraction points to other onsite locations.

Project footprints on water resources may be reduced during construction by BMPs such as:

- Install mechanisms to reclaim treated groundwater for onsite use such as dust control, vegetation irrigation, or process input for other treatment systems
- Devise methods to re-inject uncontaminated groundwater that was pumped solely for the purpose of depressing the water table (and consequently preventing upwelling) rather than discharging it to the POTW
- Create grassed swales or grass-lined channels outside the treatment area, to minimize incoming stormwater runoff and route it to landscaped areas for gradual infiltration or evapotranspiration, and
- Choose porous asphalt that allows water percolation, rather than impermeable concrete, to cover ground surfaces of adjacent work or storage areas.

Additional BMPs regarding treatment, conservation and management of water during site cleanup are available in *Green Remediation Best Management Practices: Pump and Treat Technologies.*[2e]

Operation and Maintenance

Potential inefficiencies contributing to the environmental footprint of IST applications often relate to release of contaminant vapors through vertical short-circuiting, incomplete treatment of off-gases, or migration of vapors beyond the treatment zone. Unintended vapor emissions or system inefficiencies can be reduced by BMPs such as:

- Consider adding a low-permeability soil cap at an area with negative pressure to prevent intrusion of clean air that can short circuit the extraction system
- Assure that the zone of influence of vapor extraction wells completely covers the treatment area
- Properly maintain surface seals around all wells and monitoring points
- Avoid or minimize dewatering when lowering of the water table is unneeded to treat the smear zone or otherwise unnecessary, by reducing the applied vacuum or installing additional extraction vents
- Maintain flow rates sufficient to prevent vapors from migrating beyond the treatment area without overloading the treatment system
- Regenerate adsorbtive media such as GAC filters, and
- Modify the vapor treatment system as needed, to accommodate changing influent vapor concentrations as treatment progresses.

Periodic remedial system evaluation can help identify BMPs to improve performance and efficiency of IST system operations (including vapor or dual-phase extraction processes) as cleanup progresses, such as:

- Re-evaluate efficacy of the air/vapor treatment on a periodic basis, to identify any opportunity for reduced material use or waste generation
- Periodically re-sample groundwater of a dual-phase extraction system to assure adequate characterization and treatment of light non-aqueous phase liquid (LNAPL); for example, mineral spirit LNAPL associated with VOC contamination can generate a need for increased backwashing
- Adjust flow rates as needed to obtain the minimum air flow and maximum amount of contaminants per volume of vapor removed
- Shut down equipment no longer needed; for example, electrodes or recovery wells in some areas may be shut down as soon as performance levels are met while others continue to operate
- Modify any wells no longer contributing contaminants within a given manifold system, despite proper well functioning, or take them offline, and
- Develop an exit strategy, including performance values that trigger termination of the active heating process; for example, a pre-defined level of diminishing returns could prompt heating system shutdown and conversion to one or more remediation "polishing" technologies with a smaller environmental footprint.

Monitoring

Decreases in field visit frequency and associated fuel and material consumption or waste generation during system monitoring can be achieved through BMPs such as:

- Increase automation through use of equipment such as electronic pressure transducers and thermo-couples with an automatic data logger (rather than manual readings) to record data at frequent intervals
- Use electrical resistance tomography to monitor soil moisture levels that may vary over time, which affects the project's soil resistivity estimates and associated energy demands
- Use field test kits or analyze for only indicator compounds whenever possible
- Monitor soil temperatures on a regular basis to assure uniform heating in target areas and avoid unexpected heating and energy waste in non-targeted areas, and
- Use a control system that can be remotely accessed to avoid bringing staff to the site daily.

Implementing In Situ Thermal Technologies: Recommended Checklist
Design
✓ Establish a conceptual site model ✓ Maximize use of high-resolution imagery techniques ✓ Consider a phased heating approach ✓ Integrate sources of renewable energy ✓ Establish a baseline on resource consumption and waste generation
Construction
✓ Consider co-locating wells with heating equipment ✓ Choose materials with recycled contents ✓ Employ direct-push technology wherever feasible ✓ Screen drill cuttings for potential onsite reuse ✓ Integrate techniques to lower or buffer noise ✓ Reclaim treated or clean pumped water for onsite use or return to the aquifer ✓ Employ cleaner fuels, clean emission technologies, and fuel conservation techniques
Operation and maintenance
✓ Maintain surface seals ✓ Modify flow rates to meet changing site conditions ✓ Continuously evaluate the potential for downsizing or shutting down equipment as cleanup progresses
Monitoring
✓ Maximize automated and remote monitoring capabilities ✓ Use field test kits whenever feasible ✓ Include data collection from areas immediately beyond the target area

Natural resource efficiencies during IST implementation can be gained through acquisition of environmentally preferable goods and services. EPA's ***Green Response and Remedial Action Contracting and Administrative Toolkit*** *contains sample language for cleanup contracts and potential reporting structures to help track associated environmental improvements.[10] Use of a performance-based contract with clear criteria such as target heating temperatures can also help assure a minimized environmental footprint while controlling costs throughout the life of an IST project.*

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EPA/OSWER appreciates the many contributions to this fact sheet, as provided by EPA regions and laboratories or private industry.

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Office of Solid Waste and Emergency Response (5203P)

EPA 542-F-13-003
December 2013

Green Remediation Best Management Practices:
Materials and Waste Management

Office of Superfund Remediation and Technology Innovation — Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outline the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) identified in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis, while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.

The use of non-renewable materials such as minerals, metals, and fossil fuel-derived products has significantly increased in the United States over recent decades. In 1900, for example, 41% of the materials used in the United States consisted of renewable resources such as agricultural, fishery, and forestry products. By 1995, renewable resources accounted for only 6%.[2] Much of this increase is due to the rapid growth of manufacturing processes that consume nonfuel minerals. Currently, more than 25,000 pounds per capita of new nonfuel minerals are extracted from the earth each year as input for manufactured products used in the United States.

Increased reliance on non-renewable resources and accelerated consumption of raw, processed, and manufactured materials has led to adverse environmental effects. The effects include habitat destruction, biodiversity loss, over-stressed fisheries, desertification, and greenhouse gas (GHG) emission. In 2006, materials management accounted for 42% of GHG emissions in the United States.[3]

Materials management refers to the control of material resources throughout their life cycle as they flow through the economy, from extraction or harvest through production and transport of goods, provision of services, reuse of materials, and, if necessary, disposal.

The process of cleaning up a contaminated site often involves purchasing and consuming large volumes of manufactured items as well as raw or processed resources. Site cleanup can also generate significant volumes of waste such as:

- Industrial materials and products accumulated as debris during onsite demolition of structures and during remedy construction
- Organic materials such as wood and plant matter displaced during excavation
- Metal, glass, plastic, or paper containers and packaging from single-use products, including field supplies such as test kits for soil or water sampling, and
- Expended products such as fabric tarps and metal tooling or chemical solutions used to clean equipment or treat contaminated environmental media.

Much of this waste could be recycled or salvaged for reuse rather than disposed of at landfills.

Techniques for sustainable materials management can help reduce the environmental footprint of a cleanup. EPA's *Methodology for Understanding and Reducing a Project's Environmental Footprint* specifies seven metrics associated with materials and waste, which together constitute a core element of greener cleanups.[4]

Materials & Waste: Environmental Footprint Metrics & Units of Measure
1) Refined materials used on site (tons)
2) Refined materials from recycled or waste material (percent)
3) Unrefined materials used on site (tons)
4) Unrefined materials from recycled or waste material (percent)
5) Onsite hazardous waste generated (tons)
6) Onsite non-hazardous waste generated (tons)
7) Total potential onsite waste recycled or reused (percent)

Industrial materials salvaged from demolition activities, for example, can be reused to construct new buildings and transportation systems, enhance infrastructure for water storage or drainage, or provide supplies for local agriculture, while remaining consistent with state regulations and appropriate environmental considerations.[5] Similarly, organic matter can be reused as remediation material or site restoration components, and other solid or liquid wastes can be recycled.

EPA's suite of green remediation BMPs describes specific techniques or tools to achieve a greener cleanup.[6] Opportunities to reduce the environmental footprint associated with materials and waste focus on:

- ***Purchase of greener products***, and
- ***Material reuse or recycling versus disposal***.

Purchase of Greener Products

Implementation of green remediation BMPs should begin during planning stages of a cleanup, to facilitate sustainable materials management throughout remedy construction and maintenance. Key BMPs to reduce purchasing of virgin resources include:

- Survey onsite buildings and infrastructures to determine the potential to reuse existing structures and equipment or their components as a substitute for virgin materials
- Investigate potential offsite sources such as nearby facilities that may have surplus inventory or are undergoing decommissioning, for additional substitutes
- Check for availability of needed products at local non-profit or retail centers that facilitate product reuse
- Select products that are environmentally preferable (when compared to other products serving the same purpose) with respect to raw materials consumption, manufacturing processes and locations, packaging, distribution, recycled content and recycling capability, maintenance needs, and disposal procedures
- Choose vendors with production and distribution centers near the site, to minimize fuel consumption associated with delivery
- Choose suppliers that will take back scraps or unused materials
- Design new construction to utilize standard material sizes, which minimizes excess purchasing volumes and avoids waste from custom sizing, and
- Plan new construction with future deconstruction or material reuse in mind.

EPA recommends taking advantage of existing resources to help select and purchase environmentally preferred products. The U.S. General Services Administration (GSA), for example, offers the Sustainable Facilities Tool (SF Tool), a comprehensive, online source of information and electronic links on materials for constructing and operating buildings or conducting facility activities in a sustainable way.[7] Product categories in the SF Tool's "green production compilation" area cover a range of topics, including construction materials, landscaping elements such as compost and fertilizers, cleaning products, HVAC/mechanical equipment, and non-paper office products. The tool includes a search function to identify specific items such as fencing, signage, and bioremediation materials.

Environmental programs and standards captured within the tool include the:

- Design for the Environment (DfE) Program safety screening for lower hazard products
- Biopreferred® Program for products with biobased content
- WaterSense® performance testing for water-efficient products
- Federal Energy Management Program (FEMP) for water- and energy-efficient products
- ENERGY STAR verified ratings for energy-efficient products
- Significant New Alternatives Policy (SNAP) Program for ozone-depleting chemical substitutes, and
- American National Standards Institute (ANSI), Green Seal, and other independent certification programs.

A pump-and-treat (P&T) system to treat contaminated groundwater at the ***Lawrence Aviation Site*** *on Long Island, New York, consists of equipment previously used elsewhere in the community:*

- *An air stripper salvaged from a local dry cleaning facility; the unit is equipped with two 3,000-pound filtration vessels containing reactivated (instead of virgin) carbon to treat air prior to its emission from the plant, and*
- *Two aqueous-phase carbon vessels, a vapor-phase carbon vessel, bag filters, a blower, piping, valves, connectors, pumps, and electrical wiring reclaimed from a nearby manufacturing facility undergoing upgrades.*

Construction of a building to house the P&T system involved use of greener products and salvaged construction materials:

- *Lumber from a Certified Green Dealer™ lumberyard and wood certified under the Sustainable Forestry Initiative® or Program for Endorsement of Forest Certification*
- *Low-maintenance, insect- and weather-resistant composite siding made of sustainable materials with low toxicity, such as wood pulp, cement, and sand*
- *Spray-foam insulation made of renewable resources (soybeans) and through processes involving no formaldehyde, petroleum, asbestos, fiberglass, or volatile organic compounds*
- *Common-area flooring made of rapidly renewable cork, with an underlayment of post-consumer recycled granulated rubber from tires*
- *Light-reflective ceiling tiles comprising 45% rapidly renewable resources and 23% recycled content*
- *Cabinetry, hurricane shutters, and exterior doors made of remnant framing lumber instead of virgin wood, and*
- *Landscape mulch containing chipped wood from selected onsite trees requiring removal before remedy construction.*

During construction, 240 tons of soil requiring excavation was transferred and stockpiled at a nearby municipal property for use by the Port Jefferson Highway Department. Prior to transfer, analytical tests were conducted on the soil to assure no residual contamination.

Material Reuse or Recycling Versus Disposal

Green remediation BMPs to facilitate sound planning for material reuse or recycling include:

- Check with applicable state agencies and local authorities to assure acceptable reuse of non-routine waste material or of industrial materials salvaged during construction and demolition (C&D)
- Screen local recyclers and waste haulers to identify organizations that will handle materials in an environmentally responsible manner, including suitable transportation methods and waste destinations, and
- Evaluate environmental or other trade-offs involved in onsite reuse of materials versus shipment offsite for reuse and/or recycling; evaluations can range in level of effort from qualitative comparisons of options to more rigorous quantification of alternative outcomes.[4]

Sustainable materials management can be facilitated through specific procurement practices for cleanup services, including subcontracts; for example:

- Include a requirement for reuse and recycling of all uncontaminated C&D material in documents such as requests for proposals and bid specifications
- Specify materials management goals in documentation such as construction waste management plans
- Develop a plan and reporting format to routinely track materials reuse/recycling and disposal, and
- Consider performance-based service contracts that can additionally motivate cleanup contractors and subcontractors to maximize material reuse/recycling.

EPA's **Greener Cleanups: Contracting and Administrative Toolkit** *provides sample contract language and criteria for sustainable materials management in EPA regions.*[8]

EPA recommends implementing additional BMPs during remedy construction, which may include demolition of existing structures:

- Divert at least 50% (by weight) of the uncontaminated C&D materials generated at the site, and include this goal in the site waste management plan
- Implement deconstruction techniques that involve preserving useable portions of existing structures, dismantling unusable parts for optimized transport, and recovering clean materials
- Salvage and sort clean materials with potential value for onsite reuse, recycling, resale, or donation
- Link a deconstruction project with a current construction or renovation project to facilitate material reuse
- Use crushed concrete as a construction aggregate for road base, pipe bedding, or landscaping
- Use concrete containing secondary cementitious materials to displace a portion of traditional Portland cement
- Use reclaimed asphalt pavement as a granular base for new roads
- Use shredded scrap tires, crushed concrete, and other onsite clean hard materials in place of borrow for fills
- Salvage uncontaminated and pest- or disease-free organic debris for use as infill or mulch as needed
- Optimize product ordering, to prevent purchase and delivery of excess materials, and
- Post onsite signage to designate collection points for routine recycling of single-use items such as metal, plastic, and glass containers, paper and cardboard, and other items that may be locally recyclable.

A comprehensive list of tools and resources for sustainable materials management decision-making is available in EPA's **Sustainable Materials Management in Site Cleanup** *engineering issue paper.*[9] *The information focuses on materials reuse and recycling and addresses topics such as:*

- *Locating C&D recyclers and material exchange networks*
- *State program requirements and beneficial use of materials*
- *Environmental benefits of diverting materials from landfills.*

Sustainable materials management, whether focused on greener product selection or waste reduction techniques, also applies to methods for treating contaminated soil, sediment, or groundwater. For example, the following BMPs may be used for remedy operation and maintenance:

- Use reconstituted reactive media whenever feasible; for example, regenerated rather than virgin granular activated carbon (GAC) can be used in carbon treatment beds or canisters
- Consider non fossil fuel-based substitutes as reactive media, such as locally available coconut shell-derived GAC rather than coal-based GAC
- Explore innovative technology enabling recycling or resale of extracted chemicals; for example, cryogenic compression and condensation processes can enable recovery of hydrocarbon from air stripping condensate[10]
- Maximize use of industrial materials (in ways consistent with agronomic and environmental constraints) such as iron and steel foundry sands, dry wall, flue gas desulfurization (FGD) gypsum, and non-synthetic compost for soil amendments and manufactured soils; FGD gypsum can also serve effectively in flow-through curtains to mitigate phosphorous transport to surface and groundwater
- Use periodic optimization evaluations as opportunities to incorporate industrial material recycling practices and to switch to newer green products, and
- Use continuous process monitoring techniques to maximize capacity of a treatment medium and minimize frequency of treatment media replacement or replenishment.

A range of industrial materials may exist as waste at sites undergoing cleanup. Conversely, industrial materials can effectively contribute to site cleanup. EPA's ***Industrial Materials Recycling*** *website provides more information on recycling and beneficial use of industrial materials such as C&D materials, coal combustion products, foundry sand, and iron and steel slag.*[5]

Cleanup at the ***Sanford Gasification Plant*** *in Seminole County, Florida, incorporated a sustainable materials management plan involving extensive reuse or recycling of onsite materials; minimized offsite disposal of excavated materials; and overall reductions in consumption of water and fossil fuels. The implemented BMPs and associated results included:*

- *Screened clean versus contaminated soil through a "cut line" investigative approach and segregated soils accordingly, which minimized the soil treatment load while averting import of 1,600 cubic yards of non-native soils for site restoration*
- *Used granulated blast furnace slag in lieu of a portion of the cement specified in the typical formula used to stabilize coal tar-contaminated soil, avoiding 13,700 tons of carbon dioxide (CO_2) otherwise emitted by thermal reactions during mixing of cement with other reagents*
- *Chipped and sent 5,000 cubic yards of extracted trees and stumps to local landscapers for use as mulch, avoiding shipment of 800 tons of material to landfills*
- *Installed a solar-powered backup energy system for perimeter air monitoring during remedy construction*
- *Reused 3.7 million gallons of water from onsite dewatering operations in the soil stabilization process*
- *Used B20 (20% biodiesel) to operate diesel vehicles and machinery, averting 177 tons of CO_2 emissions, and*
- *Procured 75% of the remedial labor and supplies (valued at $8 million) from local sources within 50 miles of the site.*

A gravity drain network overlaying recycled concrete was used to divert 500 feet of an onsite creek during remedy construction, which reduced use of diesel pumps.

The stabilization project involved extensive use of recycled concrete serving as riprap to armor the creek bed and limit erosion.

Materials and Waste Management: Recommended Checklist

Purchase of Greener Products

- ✓ Explore options for reusing materials onsite or available from local sources
- ✓ Purchase from local vendors who accept unused materials upon project completion
- ✓ Design for optimized product sizing and product ordering and for future reuse or repurposing
- ✓ Choose environmentally preferable products

Material Reuse or Recycling Versus Disposal

- ✓ Verify acceptable reuse of C&D materials with regulators
- ✓ Screen recyclers and waste haulers
- ✓ Evaluate environmental trade-offs
- ✓ Specify requirements and goals in service contracts
- ✓ Salvage uncontaminated demolition and other materials with value for reuse/recycling, resale, or donation
- ✓ Use onsite or offsite industrial materials such as crushed concrete and shredded scrap tires for remedy construction
- ✓ Recycle routine single-use items regularly
- ✓ Minimize direct or indirect use of fossil fuels during activities such as product purchasing or waste transfer
- ✓ Plan treatment process optimization and monitoring that includes sustainable materials management

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