United States Environmental Protection Agency

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]

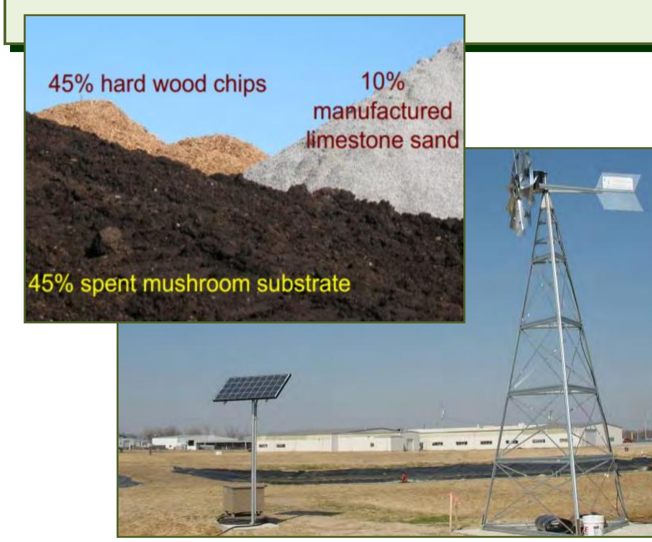
Using Passive Treatment Systems

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.

References [Web accessed: September 2012]

1. U.S. EPA; *Principles for Greener Cleanups;* August 27, 2009; http://www.epa.gov/oswer/greenercleanups
2. Abandoned Mine Lands Portal; http://www.abandonedmines.gov/ep.html
3. U.S. EPA; *Green Remediation Best Management Practices:*
   - [a] *Clean Fuel & Emission Technologies for Site Cleanup;* EPA 542-F-10-008; August 2010
   - [b] *Integrating Renewable Energy into Site Cleanup*; EPA 542-F-11-006; April 2011
   - [c] *Pump and Treat Technologies*; EPA 542-F-009-005; December 2009
   - [d] *Site Investigation*; EPA 542-F-09-004; December 2009
   - [e] *Landfill Cover Systems & Energy Production*; EPA 542-F-11-024; December 2011
4. U.S. Department of Energy; *Environmentally Friendly Drilling System Program: Balancing Environmental Tradeoffs*; June 2011
5. U.S. EPA; CLU-IN Green Remediation Focus; DeSale Restoration Area; http://www.cluin.org/greenremediation/subtab_d20.cfm
6. "Banana Peel Applied to the Solid Phase Extraction of Copper and Lead from River Water: Preconcentration of Metal Ions with a Fruit Waste;" Renata S.D. Castro et al.; *Industrial & Engineering Chemistry Research*; 2011, 50 (6), 3446–3451
7. U.S. EPA; Palmerton Zinc Pile, Superfund Case Study; February 2011; EPA 542-F-11-005
8. U.S. EPA; U.S. Abandoned Coal Mine Methane Recovery Project Opportunities; EPA 430-R-08-002; July 2008; http://www.epa.gov/coalbed/docs/cmm_recovery_opps.pdf
9. U.S. EPA; RE-Powering America's Land; http://www.epa.gov/oswercpa/index.htm
10. U.S. EPA; CLU-IN Green Remediation Focus; Elizabeth Mine; http://www.cluin.org/greenremediation/subtab_d36.cfm

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.

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

For more information, contact:
Carlos Pachon, OSWER/OSRTI (pachon.carlos@epa.gov)
U.S. Environmental Protection Agency