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

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

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

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