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Green Remediation Best Management Practices: Soil Vapor Extraction & Other Air-Driven Systems

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

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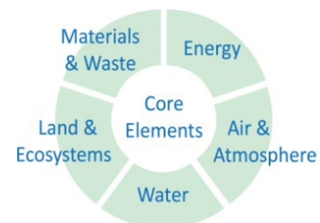
The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outline the Agency's policy for evaluating and minimizing the environmental footprint of activities involved in cleaning up contaminated sites.[1] Best management practices (BMPs) of green remediation involve specific activities 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.



BMPs involving use of renewable energy, green infrastructure or carbon sequestering vegetation during site cleanup and restoration also may help mitigate and adapt to ongoing climate change.

Overview

Soil vapor extraction (SVE) is used at certain sites to address volatile organic compounds (VOCs) that are sorbed to soil within the unsaturated zone.[2] An SVE system extracts air from, or sometimes injects air into, the vadose zone to strip the VOCs from soil and transfer the vapors to an aboveground treatment system for destruction or recovery. In contrast, air sparging (AS) involves injecting air into contaminated groundwater to drive volatile and semi-volatile contaminants into the overlying vadose zone by way of volatilization. The vapors are then removed from the vadose zone, typically by a co-located SVE system. Cleanup at some sites also may require mitigation of vapor intrusion (VI) into nearby buildings until remediation of soil or groundwater is complete. Removal of vapors beneath a building may involve an active technology such as operating a blower, a passive technology such as installing a vapor barrier or a combination of active and passive technologies.

The environmental footprint of collecting and treating the vapors typically includes high usage of electricity and fuel. As a result, a significant portion of the footprint encompasses the direct emissions due to onsite burning of fossil fuels and the indirect emissions associated with offsite production or processing of the supplied electricity or fuels. The wastewater and material wastes generated during operation of air-driven systems primarily result from the treatment process, which commonly involves granular activated carbon (GAC) adsorption or to a lesser extent thermal or catalytic oxidation.

A Sampling of Electricity Used by SVE System Components over Three Years (in kilowatt-hours (kWh))

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 usage: 232,800 kWh (equivalent to annual usage by about 30 homes)[3]
Estimated carbon dioxide emission: 182 tons

EPA's *Greener Cleanup Metrics Workbook* provides a means to collect and track site-specific information on 14 universal metrics concerning use of energy, materials and water and generation of waste during site cleanup.[4]

The ASTM *Standard Guide for Greener Cleanups* (E2893-16) may be used to screen and prioritize BMPs at a site where SVE or other air-driven remediation systems are planned or operating. Where needed, the standard guide's process for integrating a quantitative evaluation of a project's environmental footprint can be used to weigh individual contributions to the footprint.[5]

Project Planning

The environmental footprint of implementing SVE or other air-driven technologies may be minimized by incorporating BMPs early in the project, when designing the remedial system and planning its construction. Relevant BMPs focused on minimizing usage of energy, water and material resources could include:

- Design a modular network of piping that allows for future increases or decreases in air extraction or injection rates.
- Install nested SVE/AS wells or shallow/deep wells within the same borehole, to minimize construction of new wells.

- Evaluate resource tradeoffs associated with constructing and operating a high number of AS venting wells, which may decrease the system's flow of applied energy but increase material usage.
- Evaluate potential use of passive technologies for SVE or VI mitigation as stand-alone systems or as components of active SVE or VI mitigation systems, thereby reducing energy use.
- Install a source of renewable energy such as photovoltaic (PV) arrays, mechanical windmills or wind turbines to directly power some or all equipment needed for extracting or injecting air or for transferring and treating collected vapors.
- Integrate treatment of the collected vapors with treatment of off-gases from other operating remedial systems, to gain efficiencies through economy of scale.
- Identify beneficial use of groundwater that is extracted for the purpose of depressing the water table and preventing upwelling in the air extraction/injection zone.
- Establish decision points that could trigger a future change in the vapor treatment approach, such as switching from thermal oxidation to GAC media, or a transition to a remediation "polishing" technology using less natural or processed resources.
- Identify potential reuse of air-exchange wells or auxiliary piping after SVE or AS operations cease, based on the site's anticipated future use and supporting infrastructure.

Other BMPs warranting early consideration concern the efficiencies of particular SVE or AS components. For example:

- Use piping of sufficient diameter to minimize pressure drops and resulting need for additional energy to operate air blowers.
- Select vacuum pumps and blowers that can accommodate changes in operating requirements as treatment progresses. A series of multiple low-flow blowers also may provide such flexibility.
- Install motors equipped with variable frequency drives that automatically adjust energy use to meet the system's demand.
- Use a closed-loop process allowing condenser water to be recycled as supplemental cooling water.
- Treat accumulating condensate onsite, which avoids the use of fuel for transferring condensate to an offsite treatment facility.
- Integrate a heat exchanger to recover the heat in a direct-fired thermal oxidizer's exhaust and beneficially use the heat to raise the temperature of incoming air.
- Minimize the size of equipment housing and incorporate energy-efficiency elements such as thermal insulation and passive lighting into the housing design.

Onsite pilot testing of SVE or AS operations is recommended to:

- Assure suitable sizing of air extraction or injection equipment, which will help optimize energy use.
- Determine the minimum air flow rate that can meet the cleanup objectives and schedule while minimizing energy consumption.
- Identify any opportunity to reduce resource use or waste generation associated with vapor treatment.
- Establish a project baseline on information such as electricity, water and material usage and the volume of waste requiring offsite disposal.

Construction of Air-Driven Remedial Systems

Many of the opportunities to reduce the environmental footprint of constructing an SVE or AS system concern installation of wells. Relevant BMPs include:

- Deploy machinery and trucks equipped with relatively new or rebuilt engines meeting cleaner emission standards and with advanced technologies to treat engine exhaust.
- Deploy direct-push technology (DPT) rather than rotary drilling rigs wherever feasible, which significantly reduces drill cuttings and associated waste disposal, avoids use and disposal of drilling fluids, and reduces drilling duration and associated fuel usage.

AS and SVE operations over 18 months at the former Alameda Naval Air Station in California were powered by an off-grid, transportable 6 kW solar electric system providing 24 to 30 kWh of energy each day. The system's controller continually modulated the speed of a 3-horsepower, three-phase air blower connected to an 8-well manifold. The solar energy system also powered a 2.2 kW regenerative blower with a maximum flow of 70 cubic feet per minute. This enabled automatic adjustment of blowing speeds to accommodate varying amounts of solar energy available during daylight hours. Upon AS and SVE shutdown, components of the solar power system were transferred to other sites undergoing remediation.

[image credit: Sustainable Technologies]

Cleanup at the State Road 114 Superfund site in Levelland, Texas, includes operation of a 62-well SVE system and a co-located groundwater pump and treat (P&T) system to address 1,2-dichloroethane and benzene plumes in the underlying Ogallala Aquifer. Vapors from the SVE well network and the P&T system's air stripper were collected and condensed by utilizing cryogenic compression and condensation (C3) technology. This approach avoided air emissions from the treatment plant while recovering contaminant vapors as a liquid with resale value. During the first year of operation, revenue gained by resale of recovered hydrocarbon offset nearly 70 percent of the SVE system's electricity costs. The C3 system recovered more than 300,000 gallons of liquid during its four-year deployment.

- Integrate check valves in well casings to promote barometric pumping where appropriate as part of a passive SVE system.
- Choose hydraulic fluids that are biodegradable when operating hydraulic equipment or machinery such as drill rigs.
- Minimize engine idling through techniques such as manual or automated shutdown of machinery not actively engaged for a predetermined time period.
- Segregate and stockpile drill cuttings to facilitate reuse of material deemed uncontaminated.

Additional BMPs concern site preparation or a broad range of construction activities. For example:

- Lay synthetic barriers and fluid collection systems on ground surfaces of staging and work areas, to avoid introducing toxic materials to soil, groundwater or nearby vegetation.
- Limit removal of trees expected to obstruct remedial activities, to preserve ecosystem services such as cooling and shading and aid sequestration of atmospheric carbon.
- Transplant obstructing non-invasive shrubs and forbs to other onsite locations, to further preserve ecological habitat and biodiversity, foster stormwater infiltration, and sequester atmospheric carbon.
- Use pervious concrete, porous asphalt or permeable interlocking pavers rather than impervious concrete whenever feasible in areas requiring surfacing, to promote stormwater infiltration and prevent runoff-related erosion.
- Repurpose existing concrete slabs in lieu of pouring new concrete to create equipment pads. Alternatively, salvage the blocks or rubble from unusable concrete for use in other construction activities or site restoration.

System O&M and Monitoring

BMPS can be integrated into operation and management (O&M) work plans to address the environmental footprint of short- or long-term operation of an air-driven remedial system. BMPs to minimize remedial activity disturbance to ongoing site activities, nearby residences or businesses and resident or migratory wildlife include:

- Install mufflers in air exhaust lines.
- Outfit noisy equipment such as compressors with silencers.
- Integrate sound absorbers or barriers into the housings of noisy equipment.
- Use centrifugal blowers, which are quieter than positive displacement blowers with intake mufflers.
- Limit the use of artificial lighting.
- Install nest boxes at safe locations to discourage bird nesting on or near system equipment.

BMPs concerning energy and material usage during O&M activities include:

- Maintain effective surface seals around all wells and monitoring points to ensure no air loss.
- Use solar power packs to operate equipment with low energy demands, such as security lighting and system telemetry.
- Evaluate use of regenerated rather than virgin materials as adsorbtive media in the air or wastewater treatment process, such as reconstituted GAC. Potential factors include the water, energy or chemical usage in a given regeneration process.
- Choose products and equipment that have reuse or recycling potential.

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

- Integrate passive air sampling techniques where appropriate.
- Maximize project automation by using equipment such as electronic pressure transducers and thermocouples with an automatic data logger.
- Use field test kits or analyze only indicator compounds when possible, to minimize sample packaging and fuel use associated with shipping to an offsite laboratory.

SVE typically results in initially high contaminant loading that decreases over time. BMPs to maintain or improve energy and materials efficiencies involve finding opportunities to:

- Operate electricity-driven equipment in a pulsed rather than continuous mode.
- Operate pumps and blowers during off-peak hours of electricity demand.
- Adjust operating rates periodically to minimize air flow while maximizing the amount of contaminants extracted per volume of vapor removed.

An SVE system with four extraction wells began operating at the Airport Property portion of the Tucson International Airport Area Superfund Site in 2008. The system operates in conjunction with long-term extraction and treatment of groundwater. Vapor-phase GAC adsorbtion is used to treat the extracted vapors. Since SVE startup, optimization has included:

- Adding insulation around air extraction piping to avoid pipe scaling and improve efficiency.
- Replacing the original rotary-lobe blower with a regenerative centrifugal blower with higher energy efficiency and operating capacity.
- Reducing the rate of air flow over time, which decreased energy usage and wastewater generation.
- Used a portable skid-mounted SVE unit to sequentially treat eight hotspots outside the primary SVE system's radius of influence.

Over the first 10 years of SVE operation, TCE concentrations in the extraction wells dropped from 220,000 parts per billion by volume (ppbv) to 120 ppbv.

- Modify or take offline any wells no longer contributing contaminants in a manifold system.
- Deploy a remediation technology demanding less energy, such as focused bioaugmentation, to address contaminant hotspots once the bulk of contamination is removed.
- Find other onsite or offsite use of the equipment or structural components such as blowers and piping after the system is permanently shut down and decommissioned.

The Pacific Northwest National Laboratory's *SVE System Optimization, Transition, and Closure Guidance* provides an approach to determining if an SVE system should be optimized, augmented, terminated, or replaced by a different technology.[6]

Mitigation of Vapor Intrusion

VI mitigation may entail retrofitting an existing building or integrating certain components into design and construction of a new building. Potential measures vary, depending on site conditions and building characteristics such as size, foundation type and construction style. BMPs to reduce the environmental footprint of mitigating VI could include:

- Use microscale renewable energy systems to remove contaminant vapors below or within buildings or to reduce pressure within the building's HVAC air stack, such as PV-powered basement fans or vent stack-mounted wind turbines. Such systems can supplement ventilation equipment powered by other electricity sources.
- Install an energy recovery ventilator for building ventilation. This type of ventilator captures the heating or cooling energy otherwise lost in the building's HVAC exhaust and beneficially uses the energy to precondition incoming outdoor air.
- Integrate sensor-based control technology that automatically adjusts the speed of a blower to attain the targeted pressure differential between the building and soil. This allows the blower to run at reduced speeds with a lower energy demand.
- Use solvent-free products to seal existing or newly drilled holes in concrete slabs or subfloors or to otherwise tighten the building envelope.
- Choose synthetic sub-slab vapor barriers (geomembranes) or aerated floor systems largely made of recycled plastic or other post-consumer waste.
- Use concrete mixes containing a high percentage of industrial waste by-products (as a substitute for a portion of the Portland cement) when constructing a concrete vapor barrier.
- Choose no/low VOC-emitting products when using spray-on foam to stop air leakage in small areas.

A sub-slab depressurization system began operating at the Chem-Fab Superfund Site in Doylestown, Pennsylvania, in 2017. The system uses seven high-vacuum fans and three compact radial blowers to remove VOC vapors from the sub-slab of a commercial building. Optimized electricity usage by the 2,000 watt system, which operates continuously, is aided by built-in capabilities of the selected air-exchange units. The blower units include speed controls, and the vacuum fan units can operate at different voltages. To minimize ground-level noise, each fan exhausts through a muffler above the building's roof.

Periodic optimization of an operating VI mitigation system may involve BMPs such as:

- Replace older blowers or other energy-intensive equipment with more efficient models becoming available.
- Scale down the size of electricity-driven equipment while maintaining the required rate of air flow.
- Suspend operation of a blower in a multi-blower system if discharge monitoring indicates that the blower is minimally contributing to mass flux.[7]

Bioventing and biosparging also involve active or passive air exchange processes but use the air to stimulate natural biodegradation. Bioremediation and other remediation technologies are addressed in EPA's companion fact sheets on green remediation BMPs.[8]

References

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This fact sheet provides an update on information compiled in the March 2010 "Green Remediation Best Management Practices: Soil Vapor Extraction & Air Sparging" fact sheet (EPA 542-F-10-007), in collaboration with the Greener Cleanups Subcommittee of the U.S. EPA Technical Support Project's Engineering Forum.

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