United States Environmental Protection Agency

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.*

References [Web accessed: October 2012]

1. U.S. EPA *Principles for Greener Cleanups;* August 27, 2009; http://www.epa.gov/oswer/greenercleanups
2. U.S. EPA; *Green Remediation Best Management Practices:*
   - [a] *Site Investigation*; EPA 542-F-09-004; December 2009
   - [b] *Integrating Renewable Energy into Site Cleanup*; EPA 542-F-11-006; April 2011
   - [c] Soil Vapor Extraction & Air Sparging; EPA 542-F-10-007; March 2010
   - [d] *Clean Fuel & Emission Technologies for Site Cleanup;* EPA 542-F-10-008; August 2010
   - [e] *Pump and Treat Technologies*; EPA 542-F-09-005; December 2009
3. U.S. EPA; *Site Characterization Technologies for DNAPL Investigations*; EPA 542-R-04-017; September 2004
4. U.S. EPA; CLU-IN Green Remediation Focus; Footprint Assessment: http://www.cluin.org/greenremediation/subtab_b3.cfm
5. U.S. DOE Advanced Manufacturing Office; Steam Systems; http://www1.eere.energy.gov/manufacturing/tech_deployment/steam.html
6. U.S. DOE/EERE; DOE's Best Practices Steam End User Training; September 8, 2010; http://www1.eere.energy.gov/manufacturing/pdfs/efficiencydefinition.pdf
7. U.S. DOE/EERE; Steam Generation, Distribution, Energy Use, and Recovery; http://www1.eere.energy.gov/manufacturing/tech_deployment/steambasics.html#generation
8. U.S. General Services Administration; Green Products Compilation; http://www.gsa.gov/portal/content/198257
9. U.S. Department of Transportation Federal Highway Administration; User Guidelines for Waste and Byproduct Materials in Pavement Construction; http://www.fhwa.dot.gov/publications/research/infrastructure/structures/97148/
10. U.S. EPA; *Greener Cleanups Contracting and Administrative Toolkit*; http://www.cluin.org/greenremediation/docs/Greener_Cleanups_Contracting_and_Administrative_Toolkit.pdf

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