Green Remediation and the Use of Renewable Energy Sources for Remediation Projects

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Prepared by

Amanda D. Dellens
National Network for Environmental Management Studies Fellow
Case Western Reserve University

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U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Office of Superfund Remediation and Technology Innovation
Washington, D.C.
www.epa.gov
www.clu-in.org

NOTICE

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LIST OF ABBREVIATIONS

AFB	Air Force Base
AOC	Administrative Order on Consent
ARAR	Applicable or Relevant and Appropriate Requirements
CAP	Climate Assessment Plan
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CO_2	Carbon Dioxide
CSP	Concentrating Solar Power
DCA	Dichloroethane
DNT	Dinitrotoluene
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ERH	Electrical Resistance Heating
FF	Federal Facility
FNOP	Former Nebraska Ordnance Plant
FTO	Flameless Thermal Oxidation
FUDS	Formerly Used Defense Site
GAC	Granular Activated Carbon
GCW	Groundwater Circulation Well
GSA	General Services Administration
HVDPE	High-Vacuum Dual Phase Extraction
ISRA	New Jersey Industrial Site Recovery Act
kW	Kilowatt
kWh	Kilowatt Hour
LFG	Landfill Gas
LLNL	Lawrence Livermore National Laboratory
LM	Leachate Management
MMR	Massachusetts Military Reservation
MNA	Monitored Natural Attenuation
MW	Megawatt
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NDMA	Nitrosodimethylamine
NJDEP	New Jersey Department of Environmental Protection
NPL	National Priorities List
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
OII	Operating Industries, Inc.
OSC	On-Scene Coordinator
OSWER	Office of Solid Waste and Emergency Response
OU	Operable Unit
ppm	Parts per Million
psi	Pounds per Square Inch
P&T	Pump and Treat
PCE	Perchloroethene
PSVE	Passive Soil Vapor Extraction

PV	Photovoltaic
RCRA	Resource Conservation and Recovery Act
RGGI	Regional Greenhouse Gas Initiative
RMS	Remote Monitoring System
ROD	Record of Decision
RPM	Remedial Project Manager
scfs	Standard Cubic Feet per Second
scfm	Standard Cubic Feet per Minute
SCA	St. Croix Alumina
SCDHEC	South Carolina Department of Health and Environmental Control
SCM	Site Control and Monitoring
SEIA	Solar Energy Industries Association
SO_2	Sulfur Dioxide
SRS	Savannah River Site
SVE	Soil Vapor Extraction
TCA	Trichloroethane
TCE	Trichloroethene
UST	Underground Storage Tank
VOC	Volatile Organic Compound
WDTC	Wind-Driven Turbine Compressor
WEG	Wind-Driven Electric Generator
UV/Ox	Ultraviolet/Oxidation

EXECUTIVE SUMMARY

Green remediation is the practice of considering environmental impacts of remediation activities at every stage of the remedial process in order to maximize the net environmental benefit of a cleanup. Considerations include selection of a remedy, energy requirements, efficiency of on-site activities, and reduction of impacts on surrounding areas. Remediation activities can have a negative impact on the environment, such as greenhouse gas emissions from combustible fuels used by remedial technologies or from off-site water quality impacts of cleanup activities. Furthermore, many of the pump and treat (P&T) systems currently in place were designed and installed when energy was less expensive and designers did not consider the full impacts of using non–renewable energy.

To counter these negative environmental impacts, decisions are being made at many sites to utilize alternative energy sources for powering more traditional remedial systems such as P&T and soil vapor extraction (SVE). This strategy maintains effectiveness of remediation methods while reducing emissions of greenhouse gasses from conventional power sources such as coal-fired power plants. Alternative fuels such as biofuel also are used to power heavy construction equipment, thereby reducing emissions of harmful air pollutants.

The purpose of this study is to identify cleanup projects employing renewable, sustainable energy sources and/or alternative fuels for site remediation. Limited work has been done to determine the state of the practice. As a result, this research examines EPA’s cleanup programs and regional trends to provide a clearer understanding of the state of the practice. Alternative energy use at cleanup sites is a form of green remediation that has not been adopted as frequently as other green remediation techniques; however, project managers increasingly consider use of alternative energy. Certain regions of the U.S. are better suited than others to capture solar or wind energy, thus creating more opportunities to use these technologies. A few of the projects highlighted in this report are pilot-scale studies, demonstrating the use of various technologies and providing a resource for future applications. Others are full-scale implementations of alternative energy technologies, showing a broad range of capabilities for remediation projects.

Research identified fifteen projects where renewable energy was used to power remedial systems. Nine of the projects used solar power (photovoltaics (PV)), four projects used wind power, one used landfill gas (LFG), and one used recycled vegetable oil as a fuel to power equipment. Several of these sites utilized a combination of energy sources to achieve site-specific goals. The most common contaminated media at these sites was ground water. A majority of the sites employed P&T systems, and one site used SVE. Other small uses of renewable energy at sites included irrigation and data collection. The study findings generally suggest that the use of renewable energy sources to power remediation systems is gaining ground but currently focuses on P&T systems. Findings also indicate, however, that numerous opportunities exist for expanded integration of renewable energy sources in remedy selection and design.

1. INTRODUCTION

As part of the Office of Solid Waste and Emergency Response (OSWER) approach for promoting and advancing the full suite of green remediation practices, this study determines the state of the practice of renewable energy use for remediation. Project managers may use the information collected and documented in this study as a benchmark for remediation planning that integrates these energy sources. Analysis of current activities also will aid in identifying areas of opportunity for expansion of green remediation practices. These practices can be applied to sites regulated under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, commonly known at Superfund) and Resource Conservation and Recovery Act (RCRA), as well as cleanup programs specific to underground storage tanks (USTs), federal facilities (FFs), and brownfields. With coordinated efforts, the full suite of benefits of green remediation can be achieved in cleanups under all regulatory frameworks.

Green remediation is the practice of considering the environmental effects of a remedial strategy (i.e., the remedy selected and the implementation approach) early in the process, and incorporating options to maximize the net environmental benefit of the cleanup. It should be considered in each phase of the remediation process, from the selection and design of remediation technology to the management of on-site activities and use of energy conservation and alternative energy sources. At each stage, opportunities exist to improve efficiency of traditional remedial methods as well as to utilize emerging innovative technologies.

1.1. Remedy Selection

The remedy selected for site cleanup is an important consideration with potentially significant impact on the amount of energy consumed throughout the course of a cleanup project. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) outlines nine selection criteria for a Superfund remedy (Subpart E: Hazardous Substance Response, Section 300.430) (55):

1. Be protective of human health and the environment,
2. Comply with the applicable or relevant and appropriate requirements (ARARs),
3. Be permanent and effective in the long term,
4. Reduce the toxicity, mobility, or volume of the hazardous substance, pollutant, or contaminant,
5. Be effective in the short term,
6. Be technically and administratively feasible,
7. Be cost effective,
8. Achieve state acceptance, and
9. Achieve community acceptance.

Incorporating alternative energy considerations into the remedy selection process can offer increased sustainability and long-term cost savings. Many Superfund sites are located in remote locations, where connecting to the local utility grid is expensive and sometimes impracticable. In these cases, using solar or wind power to operate low-flow pumps, irrigation, or ground-water monitoring systems is a beneficial and cost-effective alternative. Additionally, at landfill sites, off-gases often can be captured and converted to usable energy for site operations (52). These energy considerations should not alter the remedy selection criteria or process, but rather provide opportunities to increase efficiency and sustainability at a site while reducing dependency on non-renewable energy.

2. OVERVIEW OF SELECT ALTERNATIVE ENERGY TECHNOLOGIES

The sites examined in this study use various forms of alternative energy. Solar and wind power remain the most frequently used sources of renewable energy. Energy sources such as LFG (for electricity generation or direct use) and biofuels (for equipment operation) are used increasingly in general practice but not typically for remediation systems and thus are not emphasized in this report. Select case studies are included to recognize use of these technologies and their niche in the practice of green remediation. Solar, wind, LFG, and biofuels are discussed in this section to provide an overview of the available technologies; their applications will be discussed in later sections. Table 1 provides a cost comparison of these energy sources.

Energy Source	Applications	Cost (Generating Capacity)	Cost (Use)	U.S. Production
Solar	P&T, SVE, data collection, irrigation, general energy production	$8-$10 per watt	$0.04-$0.07 per kWh[1]	120 MW (PV) 2,339 MW[2] (CSP) 198 MW (solar heating)
Wind	P&T, SVE, general energy production	$2-$4 per watt	$0.20-$0.30 per kWh[1]	11,961 MW
Landfill gas	General energy production	$2-$3 per watt	$0.07-$0.09 per kWh[1]	1,195 MW
Biofuels	Equipment/vehicle operation	$1.04 per gallon[3]	$3.31 per gallon	1.39 billion gallons per year

Table 1: Alternative Energy Costs

2.1. Solar

Solar energy in the form of heat or light may be captured and converted to useable forms such as electricity through active or passive (non-mechanical) methods. Solar technologies are classified generally as either direct or indirect (involving a series of energy transformations) and range significantly in complexity and scale. Examples include: photovoltaics relying on solar-absorbent media; concentrating solar power (CSP) employing large-scale refractive surfaces such as mirrors; daylighting achieved

[1] Photovoltaic industry statistics (33).
[2] 2006 contract potential (34).
[3] U.S. Department of Energy, Energy Information Administration (EIA), Biodiesel Performance, Costs, and Use (43).

through calculated orientation of transparent and reflective surfaces; water heating/storage systems such as retention ponds or circulating-loop tanks; and hot air storage through increased thermal mass or ventilating Trombe walls.

Currently, most solar applications at remediation sites involve photovoltaics to power small pumps or monitoring systems. PV cells consist of semiconductor materials such as silicon or synthetic polymers, many of which are now enhanced by nanoscale particles. Cells range in size from that of a postage stamp to a few inches across, and are connected together to form modules that can be several feet long and a few feet wide. These modules are interlocked to form PV panel arrays offering varying levels of energy output (39). Solar arrays are constructed with either fixed or tracking tilt. Fixed-tilt units are angled to maximize sun exposure throughout the year. In contrast, tracking units employ movable parts that continuously change angles of the solar-absorbent PV surfaces to maintain maximum exposure throughout the day. Due to the moving mechanical parts, tracking units require additional operation and maintenance costs (27). Many remediation sites use stand-alone PV systems because they are ideal for remote locations where utility power is unavailable, undesirable, or too expensive (39).

PV systems also can be constructed for use in grid inter-tie mode if they are connected to the utility grid. When insufficient solar energy is available to power the remedial system, it can draw electricity from the local utility. This can be advantageous for systems with larger power requirements that cannot be supplied by solar power alone. During times of high solar energy, when the PV system generates more electricity than required by the remediation system, excess energy is delivered back into the grid for use by other utility customers (39).

Operation of a PV system connected to the utility grid costs approximately $10,000 per kilowatt (kW) of capacity. If not connected, the system requires a battery backup at significant additional costs (12). Grid-tied PV costs for U.S. county-specific commercial applications can be estimated at www.findsolar.com. The U.S. Department of Energy (DOE) aims to reduce the cost of all grid-tied PV systems from a median price of $6.25 per watt (in 2000) to $3.30 per watt by 2015 under the Solar America Initiative (25).

The Solar Energy Industries Association (SEIA) estimated in 2006 that the number of PV installations in the U.S. that year would increase 20 percent from the previous year, to 120 megawatts (MW) of direct-current electricity. SEIA also reported a significant increase in the proportion of small-scale PV systems that have tied to the utility grid since 2005 (34).

2.2. Wind

Wind power is produced by converting kinetic energy of the wind to mechanical or electrical energy. Production of wind power typically employs turbines in a relatively simply process: wind turns the blades of the turbine, consequently spinning a shaft that is connected to a ground-surface generator creating electricity. Turbine sizes are based on electricity production capacity, ranging from less than 100 kW for single private-use systems to several MW for utility-scale systems. Small turbines also can be used in conjunction with other energy generators such as PV panels or diesel generators to create hybrid systems operating independently of the utility grid. To generate large amounts of electricity, multiple turbines can be constructed together to form a wind farm. Wind turbines can operate as stand-alone systems or in grid inter-tie mode, as with solar power systems, depending on the energy demand and location of a site (41).

The cost of implementing a wind turbine for site remediation purposes may be inferred from industry estimates based on various rates of energy production in more common applications. For example, equipment and installation costs for a residential-scale (less than 10 kW) grid-connected wind turbine system range from $2,400 to $3,000 per kW. In contrast, a commercial-scale (10-100 kW) grid-connected system costs between $1,500 and $2,500 per kW, and a larger-scale system (more than 100 kW) costs $1,000-$2,000 per kW. Remote systems requiring battery storage cost on average between $4,000 and $5,000 per kW. The Iowa Energy Center estimates annual operating expenses for wind turbines to be 2-3% of the initial system cost (19).

DOE reported that a total of 11,961 MW of wind energy capacity were installed in the United States, as of May 2007. This capacity increased from 11,603 MW in 2006 and 9,149 MW in 2005 (42).

2.3. Landfill Gas

Landfill gas is generated through the decomposition of solid waste in landfills, which are located at many cleanup sites. The gas typically contains about 50% methane, one of the principle greenhouse gasses, and about 50% CO_2, another greenhouse gas contributing to global climate change. At many sites, LFG collection systems are in place to capture the gas before it enters the atmosphere, thereby reducing smog problems and greenhouse gas emissions. The gas is extracted through wells and either burned off and released into the atmosphere as CO_2 or used as energy for on-site operations. LFG can be utilized via conversion to electricity, direct use, cogeneration of electricity and thermal energy, or conversion to alternate fuels (52).

Conversion of LFG to electricity is possible through a number of technologies, depending on the scale of generation. Proven technologies include: internal combustion engines, turbines, microturbines, external combustion engines, organic Rankine cycle engines, and fuel cells. Internal combustion engines range in power from 100 kW to 3 MW; gas turbines range from 800 kW to 10.5 MW; and microturbines range from 30 kW to 250 kW (not exceeding 1 MW). Use of LFG as an alternative energy source reduces greenhouse gas emissions and contributes to cleaner air and development of greener technologies (52).

EPA estimates that the total cost for a LFG microturbine project, including installation, is between $4,000 and $5,000 per kW for systems producing less than 30 kW of energy. For larger systems (more than 200 kW), the price decreases to $2,000-$2,500 per kW (50).

As of April 2007, there were 424 operational LFG energy projects in the United States, producing a total 1,195 MW of electricity. EPA estimates that an additional 560 landfills have potential to use LFG for productive use, with a total production potential of 1,370 MW of electricity (52). Almost 100 projects are utilizing waste fuels to operate microturbines for electricity production in the United States (50).

2.4. Biofuels

Diesel fuels typically used to operate heavy machinery at cleanup sites can be replaced by renewable diesel alternatives such as biodiesel and vegetable oil. Biodiesel is derived from vegetable oil, animal fat, or waste grease and contains fatty acid methyl esters. It is generated through a process of esterification, a process by which oils (soybean, canola, sunflower, recycled cooking oil, or animal fats) are combined with an industrial alcohol and a catalyst to form fatty acid methyl esters (53).

Combination of biodiesel and regular diesel creates a hybrid fuel that burns cleaner than conventional diesel, and is created from a renewable source of energy. Blends typically are created with 5% biodiesel (B5), 20% biodiesel (B20), or 100% biodiesel (B100). EPA estimates that use of B100 biodiesel can reduce greenhouse gas emissions by 50%, as well as decrease emissions of particulate matter, carbon monoxide, and sulfates (53). DOE’s National Renewable Energy Laboratory (NREL) confirms that use of these fuels can significantly displace petroleum as a principle energy source (24).

Another form of biodiesel can be created from a blend of regular diesel and ethanol, but this combination is less stable and generally considered less safe. Raw vegetable oil can also be used as a replacement for conventional diesel fuel in machinery with engine conversions. Without conversion to fatty acid methyl esters, however, vegetable oil and recycled greases can encounter problems due to differences in viscosity and chemical makeup. To date, EPA has not certified use of vegetable-oil fuels and related vehicle conversions.

As of March 2007, the cost of biodiesel (B99-B100) per gallon was on average 26% higher than conventional diesel. Blends cost slightly less than conventional diesel: B20 cost 4% less and B2-B5 cost 1% less. DOE has determined, however, that biodiesel blends tend to cause a slight decrease in fuel efficiency (43).

As of June 2007, a total of 148 companies were actively marketing biodiesel in the U.S., with a combined capacity of 1.39 billion gallons per year. The National Biodiesel Board reported that an additional 96 companies are constructing U.S. plants which are scheduled to be operational by the end of 2008. Combined with the expansion of five existing plants, the new biodiesel plants are expected to supply an additional 1.89 billion gallons per year (23).

3. SITE DATA

Data for this study were collected from remedial project managers (RPMs) in several regions, project managers in both Superfund and RCRA cleanup programs, academic studies, and EPA's Superfund Information Systems database. Fifteen sites using alternative energy and an additional four sites currently considering alternative energy sources were identified. Appendix A of this report contains a summary of all study sites, and Appendix B comprises 14[4] case studies on these sites.

3.1. Treatment Systems Powered by Renewable Energy

Of the fifteen identified sites employing or considering alternative power sources for remediation, four use wind power and nine use solar power. One of these sites, the Savannah River Site (SRS), uses a wind turbine supplemented by a PV panel. St. Croix Alumina also uses both technologies. The remainder of the study set addressed use of vegetable oil to operate equipment at the Grove Brownfield site, and use of LFG to generate on-site power at the Operating Industries Inc. (OII) Landfill site. Figure 1 provides a breakdown of the 15 study sites based on the type of alternative energy used.

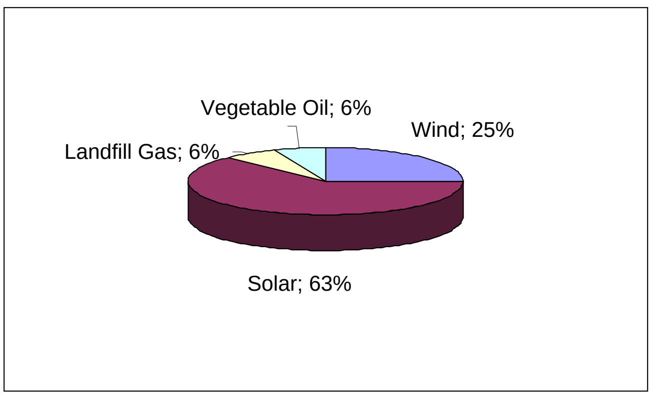

Figure 1: Alternative Energy Sources at 15 Study Sites

The end use for an alternative energy source is an important indication of how the technology may be used at sites in the future. Figure 2 provides a breakdown of the study sites by application of alternative energy.

[4] Though the Getty Gasoline site was part of the study set, an associated case study is not included in Appendix B due to limited availability of information.

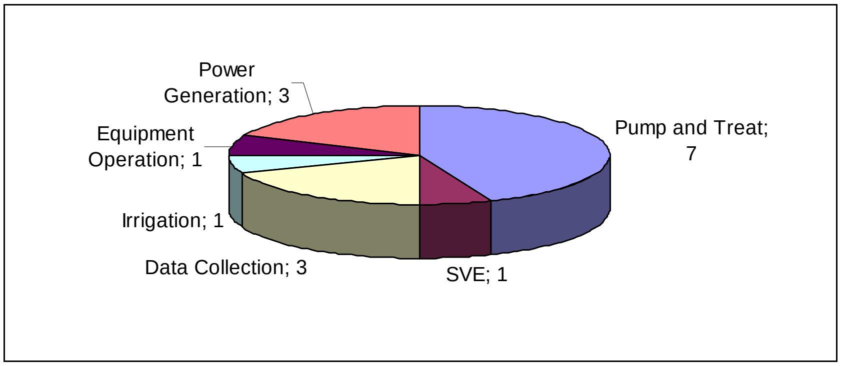

Figure 2: Alternative Energy Uses at 15 Study Sites

3.1.1. Pump and Treat

Of the fifteen study sites, seven use alternative energy sources to power P&T systems. Of these, four use solar energy, two[5] use wind energy, and one uses both wind and solar energy.

The St. Croix Alumina site, located in the Virgin Islands (EPA Region 2), utilizes four wind-driven turbine compressors (WDTCs) to drive hydraulic oil "skimmer" pumps to recover free product (oil) from ground water. This system is unique in that it does not generate electricity to power pumps; instead, it uses compressed air generated by the WDTCs. Photovoltaic arrays and wind-driven electric generators also are used at the site to power the "total fluid" submersible pumps, which recover oil, ground water, and dissolved-phase petroleum hydrocarbons (16, 17).

The Former Nebraska Ordnance Plant (FNOP), a Formerly Used Defense Site, conducted a pilot study to analyze the performance of a ground-water circulation well (GCW) powered by a 10-kW wind turbine. The turbine operated in grid inter-tie mode, supplying power to the GCW when wind power was available, and transmitting any excess power back to the utility grid. The GCW was one of two on-site units that removed trichloroethylene (TCE) from contaminated ground water (11, 54). As a pilot-study with detailed cost and performance information, this site provides a model for other sites looking to utilize wind energy.

When integrated into a remediation system, photovoltaic panels are commonly used to power low-flow pumps; the technology has potential for application at many more sites in the future. At three of the study sites, solar powered low-flow pumps are used in P&T systems. A caveat of these systems is that the pump only operates during daylight hours when sunlight is available; a battery unit is needed to store excess power for night-time operation of the pumping system. If continuous pumping is not required, substantial energy savings can be achieved by using a solar powered low-flow pump system. Systems employed at the study sites generated treatment flows ranging from 2 to 5

[5] Information for one of these sites (Getty Gasoline) was not available.

gallons per minute with a static head of 10-100 feet, depending on energy capacity and requirements of each system.

At Altus Air Force Base (AFB) in Oklahoma, a pilot-scale bioreactor is used to remove TCE from ground water. The site uses solar energy to pump water into and circulate through the bioreactor at a rate of approximately 2-3 gallons per minute from a depth of 18 feet below ground surface (54). Flow rates average approximately 928 gallons per day, a rate sufficient to maintain the treatment process without the need for continuous pumping (or associated storage batteries to accommodate night-time pumping). While energy-specific cost savings in this application are small, additional savings were achieved early in the project by avoiding construction of power lines extending from the existing utility grid to the bioreactor's remote location. (13).

Similarly, the Apache Powder Company (a Superfund site in Arizona) captures off-grid solar power to provide energy to a centrifugal pump used to recirculate water through constructed wetlands. The system is capable of pumping water at 5 gallons per minute through 100 feet of 2-inch fire hose with a head of approximately 10 feet. The pumping system operates only when the system is unable to discharge water from the wetlands back into the aquifer; pumping is initiated when water in the wetlands exceeds a nitrate discharge limit of 30 parts per million (18). Since this type of cleanup application does not require a continuously operational system, connection to the utility grid or a power storage system was not needed.

Lawrence Livermore National Laboratory (LLNL) is a federal (DOE) facility in northern California utilizing extensive P&T systems. LLNL's "Site 300" currently operates four solar-powered pumps with granular activated carbon (GAC) treatment to remove volatile organic compounds (VOCs) from ground water. Each pump extracts ground water at a rate of about 5 gallons per minute from depths of 75-100 feet. These solar-powered pumping systems are off-grid but equipped with a battery to store excess power for some operation during non-daylight hours. The LLNL Main Site (a separate and distinct site on the National Priorities List (NPL)) also uses this type of solar-powered pumping system (14).

Large-scale systems connected to the utility grid also are used for remediation projects. The BP Paulsboro site, a former petroleum and specialty-chemical storage facility, is being cleaned up by BP under the State of New Jersey's Industrial Site Recovery Act (6). Since 2003, a solar field has been used exclusively to provide energy for equipment supporting a large, on-site P&T system. About 20-25% of the energy needed for the remediation system is supplied by solar energy; remaining electricity requirements are met by additional electricity from the utility grid (7). Use of this system is expected to reduce emissions of CO_2 by 571,000 pounds per year, sulfur dioxide (SO_2) by 1,600 pounds per year, and nitrogen oxide by 1,100 pounds per year (6).

Of the fifteen sites examined in this study, the BP Paulsboro site is the largest producer of renewable energy supplied completely and directly to a remediation system. Systems with greater capacity for renewable energy production generally are those producing power for full site operations or for sale to a utility provider.

3.1.2. Soil Vapor Extraction

Only one site employs renewable energy to power an SVE system. Savannah River Site, a federal (DOE) RCRA facility in South Carolina, utilizes an innovative technology invented at DOE's Savannah River Technology Center (46). A MicroBlower is a solar-powered, low-flow, active SVE device. The unit is implemented in a system consisting of a 12- or 24-volt DC vacuum blower connected to a wellhead for extracting or injecting gasses into the vadose zone. While the SRS system operates on solar power, a small wind turbine could be used alternatively. The SRS MicroBlower operates only when solar power is available, and is not connected to a supplemental energy source. When solar power is unavailable, a passive soil vapor extraction (PSVE) system is used. PSVE, or barometric pumping, takes advantage of differences in barometric pressures between the atmosphere and the subsurface, producing natural venting cycles. When atmospheric pressure is greater than the subsurface pressure, air flows down the wells into the soil subsurface. Air flow is controlled in the well by one-way valves for air and soil-vapor flow to the surface, allowing for removal of contaminants without mechanical pumping (54).

3.1.3. Data Collection

The energy required for data collection systems at cleanup sites is small in comparison to the amount of energy required for most remediation activities, but energy and cost savings still can be achieved by using renewable energy for data collection. Costs are incurred with the installation of power lines when they are required to supply electricity for data collection in remote areas. In addition, transportation costs and fuel usage also accumulate if periodic site visits are required to collect data. Several sites have found ways to circumvent these costs and energy expenditures.

In addition to a solar-powered P&T system, SRS uses solar energy to remotely detect changes in halogenated VOC concentrations in the site's ground water. The remote monitoring system (RMS) includes components enabling wireless data collection, analysis, transmission, and management (46).

Raytheon Beech Aircraft Company has proposed the use of solar-powered ground-water monitoring systems to support its cleanup activities at a RCRA site in Colorado. Details regarding these monitoring units currently are unavailable but should be released from Raytheon as the project progresses (26).

At the Aberdeen Proving Ground federal (DOD) facility in Maryland, a solar-powered data collection system currently operates in an area known as "O-Field." A total of 12 PV panels provide power for the infrastructure to collect in-well data on water levels and various geochemical parameters. Solar power was selected as a preferable alternative to an underground electrical system due to the existence of unexploded ordnance in the subsurface and other potential hazards. EPA's Region 3 estimates that the solar system saved this Superfund site tens of thousands of dollars in capital costs (57).

3.1.4. Irrigation

Irrigation represents another relatively small part of a remediation project's total energy consumption, yet it offers the benefit of increased sustainability for a site. The Crozet Township Orchard in Virginia is the site of a Superfund removal action to remediate soil contaminated with arsenic and pesticides. Where feasible, contaminated soil was excavated and disposed off-site. Excavation is inappropriate for other portions of the site with limited access, erosion problems, or heavy forests. Phytoremediation with arsenic absorbing ferns is used in these areas for in-situ removal of contaminants from the soil. The fern irrigation system comprises both a gravity-fed process and a solar-powered process, which uses a PV array (Figure 3) and low-flow pump to deliver water from the bottom of a hill into the gravity-fed drip lines. The system irrigates 7 of the 27 900-square-foot plots at the Crozet Site (4, 5).

Figure 3: PV Array at Crozet Site
(Photo courtesy of EPA On-Scene Coordinator Myles Bartos)

3.1.5. Equipment Operation

Although this study did not focus on the use of biofuels, the Grove Brownfield site in Texas was examined to highlight the use of alternative fuels for operation of cleanup equipment, along with several sustainable technologies and methods for maximizing environmental benefits of the cleanup. Debris was removed from an extensive on-site pile through use of a tractor fueled with recycled residential-vegetable oil, reducing CO_2 emissions and petroleum-based fuel consumption. In the absence of utility power, other cleanup equipment was powered with biofuel generators and solar panels. To enhance biodegradation of contaminants, a chainsaw inoculated with fungi spore-laden oil was used to remove large vegetation no longer viable. Finally, soda bottles recovered from the on-site debris piles were used to construct floating islands, which now serve as habitats for aquatic life in the retention pond, promote bioactivity, and enhance degradation of residual contaminants (10, 30).

3.1.6. Power Generation

Two study sites use alternative energy to generate electricity for general site operations, some of which include remediation activities. At the Operating Industries, Inc. Landfill in California, microturbines produce electricity from LFG for operation of the entire site, including remedial systems and site operation and maintenance (O&M). The system is connected to the utility grid, so OII receives credits for any excess energy that the microturbines produce. The system provides an estimated 70% of the energy needed for site operations (8).

F.E. Warren Air Force Base is a FF Superfund site that has used wind power since 2005. Two on-site wind turbines supply energy for general base operations. Currently, only a small amount of the energy used for remediation and monitoring equipment can be attributed to the wind system (2, 37).

A third site uses solar energy to provide on-site power. Pemaco, a Superfund site in Maywood, California, installed a PV panel system in June 2007 to ensure that the site's emergency backup batteries remain charged at all times. Currently, the generated power is delivered back to the utility grid. In the event of an electrical emergency, the backup batteries would provide power to computers running the site's treatment plant. The treatment plant houses equipment for ground-water P&T, SVE (operational since April 2007), and an electrical resistance heating (ERH) system, which is scheduled to be operational in the summer of 2007 when required power becomes available (58).

The use of renewable energy for power generation also is in the planning and evaluation stages at Otis Air Force Base (also referred to as the Massachusetts Military Reservation or MMR), a FF Superfund site. Currently, the Air Force is evaluating a proposed wind turbine for potential effects on the PAVE PAWS radar defense system located at MMR. Though the turbine would generate sufficient electricity to satisfy all energy requirements of the site's extensive ground-water treatment systems, it is not anticipated to supply power directly to the remediation systems. The Base would instead sell the electricity to the local utility and receive an energy credit for the power supplied (20). Although the wind energy would not be used directly to remediate the site, these plans provide an important example of using available resources to increase environmental sustainability.

3.2. Energy Capacity

Total energy capacities of alternative energy systems at the fifteen study sites (excluding sites generating electricity for general site operations) range from 200 watts at Altus AFB to 275 kW at the BP Paulsboro site. System sizes for general energy production range from 420 kW at the OII Landfill to 1.32 MW at F.E. Warren AFB, which is the only study site currently operating a (wind) system capacity over one MW.

The other three study sites using wind power are the Former Nebraska Ordnance Plant, the St. Croix Alumina (SCA) Facility, and Getty Gasoline[6]. As a pilot-scale study, the FNOP application uses a 10-kW wind turbine to operate one of two ground-water circulation wells on site. SCA uses wind-driven turbine compressors to drive treatment pumps driven by air compression at a rate of 10 standard cubic feet per second (scfs) and 45 pounds per square inch (psi) of pressure. Solar units at SCA, consisting of three arrays built in 2003 with a capacity of 495 watts and three panels built in 2007 with a capacity of 330 watts, generate a total 825 watts. Capacities of all fifteen study sites are summarized in Table 2; details are provided in Appendix B.

Site	Energy Type	Capacity (kW)
Aberdeen Proving Ground O-Field	Solar	**
Altus AFB	Solar	0.20
Apache Powder	Solar	1.44
BP Paulsboro	Solar	275.00
Crozet Township Arsenic Site	Solar	0.39
Lawrence Livermore National Lab Site 300	Solar	3.20
Pemaco	Solar	3.00
Raytheon Beech Aircraft Site	Solar	**
Savannah River Site	Solar	**
F.E. Warren AFB	Wind	1,320.00
Former Nebraska Ordnance Plant	Wind	10.00
Getty Gasoline	Wind	**
St. Croix Alumina Facility	Wind/Solar	10 scfm @ 45psi 0.83kW (solar)
OII Landfill	Landfill Gas	420.00
Grove Brownfields	Vegetable Oil	**

** Capacity data not available

Table 2: Energy Capacities of Projects Analyzed

4. SITES CURRENTLY PLANNING TO USE RENEWABLES

During research for this study, four sites considering or planning the use of alternative energy were identified. These sites are in various stages of the planning process but each aims to increase its sustainability by using renewable resources. As mentioned, the Massachusetts Military Reservation plans to use a 1.65 MW wind turbine, which would provide enough energy to power all on-site remediation systems; power would be sold to the utility for energy credit to the Air Force. The Air Force currently is evaluating the system for potential impacts on the PAVE PAWS radar defense system deployed along the U.S. East Coast (20). At the time of research, a schedule for construction of this system was not yet available.

[6] Specific information was unavailable for this site.

Three other Superfund sites in EPA Region 9 are in the early stages of planning alternative energy applications. Frontier Fertilizer, in Davis, California, uses a P&T system, electrical heating, and bioremediation to remediate pesticide-contaminated soil and ground water. This eight-acre site uses approximately 1.5 MW hours per month. Photovoltaic panels are planned to be installed during the summer of 2007, but information on the size and capacity of the system was not yet available at the time of this research (3).

Casmalia Resources Site is a 252-acre, inactive, commercial hazardous-waste treatment, storage, and disposal facility in Santa Barbara County, California. Remediation efforts include several landfill caps, various site improvements, and ground-water control and treatment systems. The site is under consideration for use of wind energy to power treatment pumps, communications and office operations, and treatment monitoring systems. This wind system is in preliminary planning stages and may be subject to community objections as the project progresses (21).

Hassayampa Landfill is located approximately 40 miles west of Phoenix, Arizona. The site encompasses 47 acres formerly used for domestic and solid waste disposal, as well as a 10-acre former hazardous-waste disposal facility. SVE and P&T systems are operating to remediate soil and ground water contaminated with toluene and various halogenated VOCs. Landfill caps also are used to prevent infiltration of water into contaminated soil. Nearby biomass has significant potential for use in energy production at this site; project management is considering various aspects of such a biomass project and seeking resources to move forward (59).

5. AREAS OF OPPORTUNITY

As part of OSWER's goal of advancing the practice of green remediation, this research aims to benchmark the practice of using renewable energy for remediation. Furthermore, it aims to identify areas of opportunity for advancing these practices. Government agencies such as EPA and DOE have provided information, incentives, and initiatives to encourage the use of renewable energy. Case studies presented herein show that practices are emerging in response to evolving energy needs. In response to these changes, many commercial products such as small solar-powered ground-water pumps are becoming available. With this growth, many opportunities exist for further expansion of the practice.

5.1. Superfund Data

Data analyzed for the draft twelfth edition of EPA's Annual Status Report (to be released in Fall 2007) suggest 545 operational P&T projects and 110 operational SVE projects are covered by the Superfund program as of 2005. Based on the sample of projects collected through this research, P&T systems are the predominant treatment method for which renewable energy is used. Renewable energy sources are not as commonly used to power SVE systems, but technology is available for these applications. The high number of operating P&T and SVE systems in the Superfund program indicates that opportunities exist for expanded use of renewable energy resources. In addition to the Superfund program, EPA programs such as RCRA and UST oversee numerous sites also using P&T or SVE systems (56).

5.2. Geographic Potential

These study sites illustrate the scope of remediation work that is underway using renewable energy. Currently, eight of the ten EPA regions are conducting or overseeing at least one project that uses renewable energy sources. As discussed previously, several sites also are planning to implement renewable energy projects and many more sites have potential to use wind or solar energy to power cleanups. While every site may not be suited for these technologies, these case studies show that renewable energy can be used on a small scale to help reduce energy costs and take a step towards environmental and site sustainability. NREL estimates on the availability of wind and solar (PV) resources across the U.S. are provided in Figures 4 and 5, respectively (45).

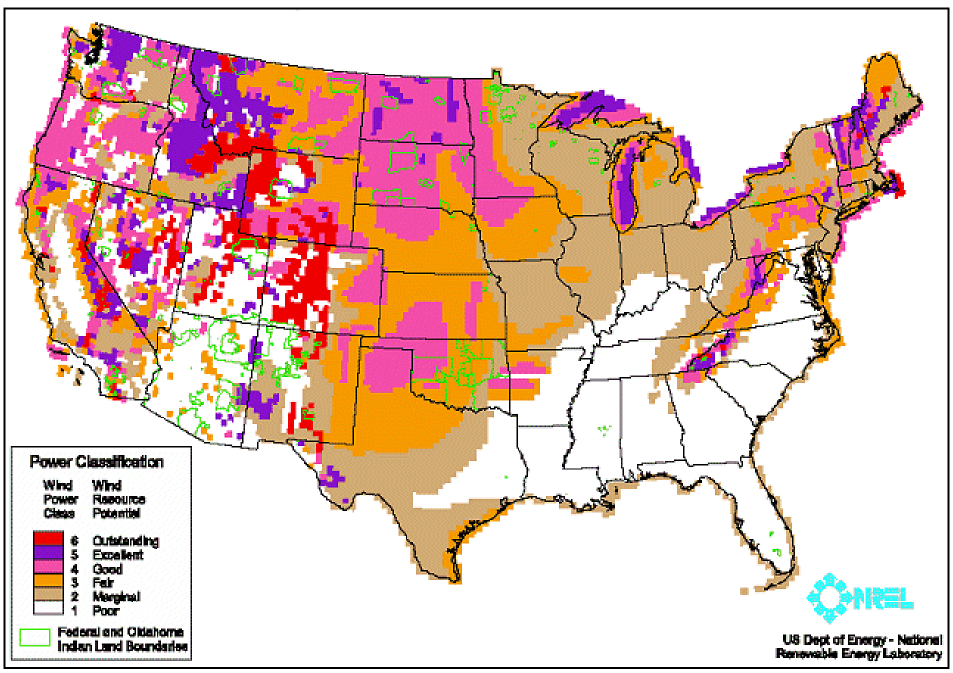

Figure 4: U.S. Wind Resource Potential

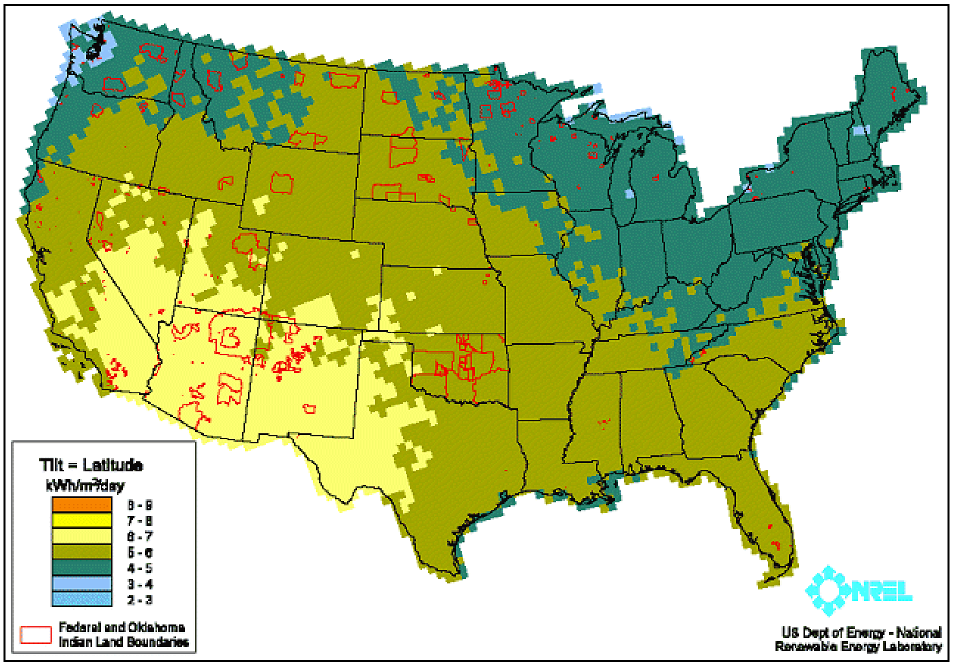

Figure 5: U.S. Solar (PV) Resource Potential

These maps show U.S. areas best suited to capture wind energy and solar energy (via PV). Though not shown, Alaska also has a large wind resource potential (1). Wind energy applications have significant potential in Alaska , where many cleanups are located in remote areas (36). Sites in the Superfund, RCRA, brownfields, UST, and federal facilities programs can use this information to determine whether alternative energy sources are feasible. Maps of solar resource potential based on calendar times and instrument orientations are available online from NREL's Renewable Resource Data Center (http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/). Maps of wind resource potential for most states are available from DOE's Wind Powering America program (http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp).

5.3. Continuing Research

Research provides numerous opportunities to identify new technologies and innovative ways to apply renewable energy and increase efficiency at remediation sites. Several published papers provide information on sustainability and efficiency issues. "Introduction to Energy Conservation and Production at Waste Cleanup Sites" (15) was developed through an EPA headquarters/regional consortium to provide project managers with information on methods for conserving energy at waste cleanup sites while still achieving remediation goals. These methods align with the framework of Executive Order 13123 (*Greening the Government Through Efficient Energy Management*) of 1999, which requires governmental agencies to expand their use of renewable energy and incorporate energy efficient practices into projects.

This study analyzed four case studies emphasizing two methods of energy production and two methods of energy conservation at waste sites. The OII Landfill (mentioned above in

Section 4.1.6) and the Douglas County Landfill in Nebraska use LFG for energy generation on site. Case studies on the Groveland Wells and Bog Creek Farms sites highlight techniques such as lump-sum O&M contracting, reuse of system components, and reduction of space-heating requirements as examples of energy conservation opportunities.

In addition to case studies, the study also reviewed examples of "remedial system evaluation" checklists used by project managers to optimize remediation systems through reductions in manpower, energy needs, and chemical use. Checklist details pertain specifically to ground-water P&T technology but similar principles could be applied to other remediation technologies.

A study presented in the American Society of Civil Engineers' *Journal of Environmental Engineering* (31) addressed the feasibility of using renewable energy to provide low-temperature heat for resistive heating elements in low-permeability silt. This technology could be implemented to enhance SVE performance, increase natural attenuation rates, and aid bioremediation, especially in colder climates. The study recognizes the environmental benefits of using renewable energy, including reduction of environmental impact, and the possibility of reusing PV modules at other sites to reduce capital costs.

Researchers designed and implemented a pilot-scale test of this low-temperature heating technology. The pilot system consisted of a hybrid energy system including a 600-watt PV array and a 1.2-meter (rotor diameter) wind turbine positioned 5 meters above ground. The test included monitoring of natural fluctuations in soil temperature, verifying performance of the PV panel, and measuring increases in soil temperatures. By supplying electricity to the resistive-element heating units in the subsurface, the system achieved soil temperature increases between 5^{o} C (0.9 meters from the heating well) and 20^{o} C (0.3 meters from the heating well). These results demonstrate that the renewable-energy soil heating system could in fact perform as hypothesized.

Another study, published in EPA's *Technology News and Trends* (54), describes use of sustainability metrics to evaluate performance and efficiency of remediation systems. Research at the Savannah River National Laboratory was used to evaluate the need for renewable energy at existing remediation sites. Analysis of an on-site P&T system demonstrated that benefits of a long-term P&T system (and other conventional treatment technologies) addressing contaminants below certain concentrations become increasingly outweighed by the treatment system's adverse environmental impacts. Researchers identified these impacts as "collateral environmental damage."

Several sustainability metrics were analyzed in this study: resource conservation, as measured by the amount of water necessary to remove one pound of contaminant; energy efficiency, measured by the amount of energy needed to remove one pound of contaminant; and carbon intensity, measured by the amount of CO_2 emitted for each pound of contaminant treated. Evaluation of these metrics concluded that resource, energy, and carbon costs increased exponentially as concentrations of contaminant decreased. Contaminant concentrations coinciding with points of exponential increases, however, remained substantially greater than the cleanup targets. This research demonstrates the need for increased use of renewable-energy powered systems and for different strategies involving energy-intensive remediation technologies. Findings also suggest that renewable-energy technologies can be used for cleanup “polishing” when contaminant levels have decreased significantly but not yet reached cleanup targets.

5.4. Limitations

Potentially limited availability of wind and solar energy poses a major limitation to use of alternative energy use. As noted above and shown in Figures 4 and 5, wind and solar energy are not readily available in all parts of the country. Battery systems must be used to store electricity created by these sources if it is not used immediately. Incorporation of storage batteries can add substantial costs to an end-user system and reduce the system’s efficiency (35). One solution practiced by many producers of wind and solar power is to connect the alternative energy system to the utility grid. This allows electricity withdrawal from the grid when insufficient amounts are produced or delivery of electricity to the grid (and use by other consumers) when excess energy is produced.

Capability for “net metering” poses a related limitation to the use of alternative energy sources. Currently, 42 states and the District of Columbia allow net metering by which excess electricity generated by grid-connected alternative sources can be sold back to the utility. Some states offer net metering for all utility types, while some only offer it for investor-owned utilities. States also differ in the maximum allowable size of alternative energy producers, whether residential or commercial (40). This limitation was encountered at Former Nebraska Ordnance Plant, where a 10-kW wind turbine was used to power a ground-water circulation well. The wind system operated in grid inter-tie mode, but the State of Nebraska does not allow for net metering. As a result, the FNOP did not receive any energy credit for energy supplied to the grid or receive the associated financial benefit (11). Though not cited as a limiting factor to the use of alternative energy by any of the sites investigated in this study, state regulations may limit ability to use alternative forms of energy for remediation purposes.

Among study sites planning to use alternative energy, one project manager cited lack of financial resources as a limiting factor. At MMR, obstacles to the use of a wind turbine system are uniquely due to proximity of a radar defense system (20); evaluations are underway to determine any potential impacts of the turbine. Another site faced community opposition to wind energy due to aesthetic impacts of the wind turbine.

Public approval has shown to be an issue when implementing alternative energy technologies. At the Casmalia Resources site, public opposition to the use of wind energy for site operations may exist due to the aesthetic impacts of a wind turbine (21). The typically large size of wind turbines creates visual obstacles, and rotation of the turbine blades causes a degree of noise. One answer to public concerns regarding construction of wind turbines may lie in education. Increased community outreach efforts could emphasize the importance of renewable energy and encourage residents and businesses to accept the visual impacts caused by turbines as a necessary sacrifice toward greater sustainability.

Public concerns also points to potential risk that wind turbines may pose to (47) in flight. The American Wind Energy Association, the primary U.S. trade organization for wind power, published an article comparing the avian threats posed by wind turbines to those posed by other human activities. Human structures and activities such as utility lines, automobiles and trucks, commercial and residential buildings, communication towers, agricultural pesticides, and cats (both feral and domestic) are responsible for tens to hundreds of millions of bird deaths each year. In comparison, an estimated 6,400 bird fatalities are attributed to commercial wind turbines. It is also noted that residential-scale turbine systems have a negligible impact on bird populations (32). DOE has determined that newer wind-turbine technology helps minimize dangers to bird species, and emphasizes that wind turbines (as with other structures) can be sited appropriately to avoid interference with major migratory pathways (41).

6. BENEFITS

Benefits of using alternative energy sources for remediation purposes include increased sustainability, reduced environmental impact, cost savings from the avoidance of additional construction, and state and federal incentives and rebates. Site-specific benefits will depend on the type and extent of remediation technology applied, location, and ongoing site activities. Some sites may benefit most from combinations of energy strategies, such as an alternative energy source with net metering capability or a hybrid system using both wind and solar energy.

6.1. Environmental Benefits

Use of both wind and solar energy provides several benefits for the environment and sustainability. First, production of electricity from either technology creates no atmospheric emissions (NO_x, SO_x, CO_2 or other contaminants such as mercury from coal-fired plants). As with most sources of energy, both technologies require initial investments in raw materials, manufacturing, and transportation of the generating equipment, which contribute a small amount to harmful air emissions. The reduced level of greenhouse-gas emissions from alternative energy producers, however, results in much smaller impacts on global climate change than those caused by conventional energy production in coal-fired power plants. Both of these alternative energy sources are renewable, generated domestically, and immediately available in abundant supply (39, 41). These technologies can reduce the impact of remediation, allowing for maximum environmental benefit while increasing sustainability of the remediation approach.

The amount of carbon emissions associated with power production can be reduced significantly through use of alternative energy sources. EPA's Clean Energy program offers a calculator (the "Power Profiler") to determine carbon emissions produced from electricity usage (at http://www.epa.gov/cleanenergy/powerprofiler.htm). This calculator shows how electricity used in a specific region compares to the national consumption average and associated emissions of CO_2, nitrogen oxide, and SO_2. Additionally, the U.S. Climate Technology Corporation offers a calculator that converts carbon emissions to comparable, recognizable equivalents, such as “passenger cars not driven for one year” or “number of tree seedlings grown for 10 years” (http://www.usctcgateway.net/tool/). These values can be used to evaluate the carbon emissions saved by using one technology over another.

Since few sites currently use renewable energy sources for remediation, conservative estimates of potential energy savings can be based on historic Superfund data (presented in Section 6.1). As a hypothetical example, it could be projected that an estimated 10% of all operational P&T systems in the Superfund program use a source of clean, renewable energy for an estimated 30 percent of the remediation system’s energy requirements. This energy consumption would equal approximately 12,838,469 kW hours per year, based on an assumed energy consumption of a typical P&T system[7]. Using a DOE Energy Information Administration estimate of 1.37 pounds of CO_2 per kW hour generated (44), the hypothetical energy savings equate to approximately 8,794.35 tons of avoided CO_2 emissions per year. These emissions savings are equivalent to the electricity consumed by approximately 1,024 households over one year, or the CO_2 sequestered by 204,567 tree seedlings over ten years of growth (38).

6.2. Economic Benefits

6.2.1. Cost Savings

Though a cost analysis was not completed as part of this research, several project managers noted that the use of renewable energy avoided costs for construction of temporary or permanent power lines connecting to the utility grid. In extremely remote locations, utility-grid connection may be cost-prohibitive or otherwise infeasible. PV units or wind turbines can contribute to cost savings and advance remediation at these types of sites. In addition, use of renewable energy sources reduces disturbance of local landscape and open space, generally creating less impact than utility lines on the surrounding area. Renewable energy use at Altus AFB in Oklahoma, Grove Brownfield in Texas, and Crozet Orchard in Virginia demonstrate these savings.

Sites requiring long-term data collection may use renewable energy to achieve savings in both cost and labor time. Several sites use on-site solar energy systems for collection of field data such as contaminant concentrations and ground-water flow rates, and in some cases for wireless data transmission to distant locations where full data analysis is conducted. These strategies reduce time and money required for frequent site visits to collect data. Costs may be reduced further by reuse of solar-equipped data collection systems at other on-site or off-site locations, or at different cleanup sites. Study sites using these strategies include SRS and Raytheon Aircraft Company.

[7] Estimate based on preliminary EPA analysis of P&T system components and related sizing/quantity, averaging annual electricity consumption of 778,089 kWh per system.

The potential for selling carbon credits for retrofitted systems offers another potential cost savings. Several emerging federal or state programs allow and regulate trading of carbon credits. As of June 2007, eight New England and mid-Atlantic states participate in the Regional Greenhouse Gas Initiative (RGGI). The RGGI has implemented a cap-and-trade program with a market-based emissions trading system that limits total emissions. but allows corporations to trade allowances of greenhouse-gas emissions (29). California, as part of its Climate Asset Plan (CAP), also has begun implementing an air emissions reduction program involving annual reductions in acceptable emission quantities, while allowing sale of emissions permits (28).

With programs like these in place, increasing opportunities have become available for implementing renewable energy. Many currently operational remediation systems draw energy from conventional power plants, and upgrading a system to use renewable energy can be costly. In some cases, upgrading may not be a cost-effective option based solely on savings from lower costs associated with conventional energy. Programs like RGGI and CAP, however, enable costs for renewable-energy retrofitting to be partially offset by potential sale of carbon credits. Using the earlier hypothetical example (Section 6.1) a total of 8,794.35 tons of CO_2 emissions could be avoided by using renewable energy for 30% of the energy needs at 10% of Superfund P&T sites. For each site, this equates to about 159.9 tons of carbon each year. Considering many P&T systems operate for 20-30 years, the opportunity cost of retrofitting a system to run on renewable energy is much less substantial. At a price of $3.75 per metric ton of CO_2 (9) a single site could save nearly $12,000 over the lifespan of a treatment system. In more mature global carbon markets, a ton of CO_2 emissions is selling for approximately $26. As the U.S. carbon market becomes more established, increased cost savings can be achieved.

6.2.2. Incentive Programs

In addition to cap-and-trade programs, several state and federal incentives are in place to promote broad-based use of alternative energy. The North Carolina Solar Center offers more information about these programs in its "Database of State Incentives for Renewables & Efficiency" (available at http://www.dsireusa.org/).

Other programs such as the EPA's Green Power Partnership support organizations purchasing or planning to purchase green power. The partnership includes Fortune 500 companies, state and local governments, trade associations, and colleges and universities (49). EPA's new Clean Energy-Environment State Partnership supports states that are developing and employing cost-effective clean energy and environmental strategies to achieve clean energy goals and public health/economic benefits (48). Fifteen states, representing half of the U.S. population and energy consumption, currently participate in this program.

The Energy Policy Act enacted on August 8, 2005, provides specific incentives for use of renewable energy, including extension of tax credits to LFG production. Currently, the Renewable Electricity Production Credit provides a tax credit of 1.5 cents per kilowatt hour (kWh) for wind, solar, closed-loop biomass, and geothermal energy production. An incentive of 1 cent per kWh is offered for electricity produced from open-loop biomass, small irrigation hydroelectric, LFG, municipal solid-waste resources, and hydropower (51). Tax incentives also are offered to distributors of biodiesel. This incentive consists of one cent per percent of biodiesel and one-half cent per percent of recycled oils in a blend, with savings then passed on to consumers (22).

7. CONCLUSIONS

The specific use of renewable energy technologies for remediation systems is a growing practice. Cleanup sites within CERCLA, RCRA, brownfields, FF, and state cleanup programs have demonstrated that the use of renewable forms of energy is an important step towards sustainability. Currently, renewable energy is characteristic of small-scale portions of larger cleanup projects. Uses such as irrigation, data collection, and low-flow pumps operating as part of a larger cleanup appear to be the most common practices. Though many sites rely on renewable energy only partially, using renewable energy in conjunction with either conventional utility-provided electricity or another form of energy appears to be most effective way of accomplishing remediation goals. Several sites demonstrate that supplementing the power supply with renewable energy can enhance energy efficiency and effectiveness of the chosen remedy.

An important follow-up step to this research is analysis of capital and O&M costs associated with these projects. These costs should be compared to those of projects using conventional energy while weighing the full suite of benefits that renewable energy offers. Variation among projects identified in this research limits generalization about the costs of remediation projects powered by renewable energy, but as the practice expands, stronger trends could be observed. This information is essential for project decision-makers when choosing how to implement a selected cleanup remedy. Additionally, it is important that EPA continues to take a leadership role in encouraging the use of renewable energy. Specifically, renewable energy considerations could be included in Superfund remedial investigations/feasibility studies (or engineering evaluation/cost analyses for removal actions) to provide further guidance for decision-makers.

Current changes in the energy market, increasing energy prices, and emphasis on global climate change offer significant opportunities for expansion of renewable energy use. The need and desire to implement available technologies already have driven the market to respond with new products and resources. Renewable energy is becoming competitive with conventional energy production, and applications in remediation are growing, as is support for their implementation. These factors indicate a great potential for renewable energy use, and the information gathered through this research can be used to support and encourage continued growth of the renewable energy market.

APPENDIX A: SITES SUMMARY

Site Name	Site Type	Location	Region	Energy Source	Treatment Method	Alternative Energy Use	Contact
Aberdeen Proving Ground O- Field	Superfund Final NPL	Edgewood, MD	3	Solar	P&T, hydraulic ground-water containment, landfill cap, removal of contaminated soils	Solar-powered data collection system	Frank Vavra
Altus AFB	FF, Non NPL	Altus, OK	6	Solar	Pilot-scale bioreactor	Solar-powered pump for ground-water circulation	Nancy Fagan
Apache Powder	Superfund Final NPL	St. David, AZ	9	Solar	P&T	Solar-powered pumps for recirculation in wetlands	Andria Benner Greg Hall
BP Paulsboro	NJDEP ISRA Voluntary	Paulsboro, NJ	2	Solar	SVE, P&T	Solar panel system providing electricity for remediation pumps	Sasa Jazic Iain Bryant
Crozet Township Arsenic Site	Removal Response	Charlottesville, VA	3	Solar	Phytoremediation with ferns	Solar- and gravity-powered irrigation system	Myles Bartos
Lawrence Livermore National Lab (Site 300)	FF Superfund Final NPL (DOE)	Livermore, CA	9	Solar	Excavation/off-site disposal, SVE, P&T	Solar-powered pumps for GAC systems	Kathy Setian Ed Folsom
Pemaco	Superfund Final NPL	Maywood, CA	9	Solar	HVDPE, UV/Ox, GAC, FTO, ERH, SVE	PV system for emergency backup battery power	Maggie Witt
Raytheon Beech Aircraft Site	RCRA Private-Party Led Cleanup	Boulder, CO	8	Solar	SVE, P&T	Solar-powered monitoring stations with wireless data-transmission well loggers	Noreen Okubo
Savannah River Site	Superfund Final NPL (DOE)	Aiken, SC	4	Solar	PSVE, MicroBlower, GeoSiphon	10 solar powered MicroBlower systems	Brian Riha Brian Looney
F.E, Warren AFB	Superfund Final NPL	Cheyenne, WY	8	Wind	Excavation, landfill disposal, landfill cap, PRB	Wind turbines for on-site power generation	Jeff Mashburn
Former Nebraska Ordnance Plant	Superfund Final NPL FUDS	Mead, NE	7	Wind	P&T	Wind turbine for GCW	Dave Drake Curt Elmore

APPENDIX A: SITES SUMMARY
(continued)

Site Name	Site Type	Location	Region	Energy Source	Treatment Method	Alternative Energy Use	Contact
Getty Gasoline[8]	SCDHEC Water Division	North Charleston, SC	4	Wind		Wind-powered pump	Dann Spariosu Lori Landmeyer
St. Croix Alumina Facility	RCRA	Kingshill, St. Croix, VI	2	Wind	P&T, recovered oil sent to HOVENSA refinery	Wind-driven turbine compressors powered by 4 large windmills	Tim Gordon
OII Landfill	Superfund Final NPL	Monterey Park, CA	9	Landfill Gas	Landfill cap, LFG collection, ground-water monitoring, MNA	Microturbines to convert LFG to electricity	Pankaj Arora Shiann-Jeng Chern
Grove Brownfield	Brownfield	Austin, TX	6	Vegetable Oil	Debris removal, ecological revitalization with native plants	Vegetable oil-powered tractor, biofuel generators, solar panels	Dorothy Crawford

Sites Currently Planning to Use Renewables:

Frontier Fertilizer	Superfund, Final NPL	Davis, CA	9	Solar	P&T, electrical heating, bioremediation	Planning installation of PV panels (size unknown)	Bonnie Arthur
Casmalia Resources	Superfund, Final NPL	Casmalia, CA	9	Wind	P&T, landfill cap, site improvements	Initial considerations of wind energy for pumps, communication and office systems, and monitoring	Russell Mechem
Massachusetts Military Reservation	FF Superfund	Barnstable Co., MA	1	Wind	excavation/off site disposal, SVE/biosparging	Planned use of wind turbine to power ground-water cleanup	Paul Marcehssault
Hassayampa Landfill	Superfund, Final NPL	Maricopa Co., AZ	9	Biomass	SVE, P&T, landfill cap	Considering use of locally available biomass as an energy source	Martin Zeleznik

[8] Site information not available

APPENDIX B: CASE STUDIES
(by energy types summarized/ordered in Table 2)

Site Name: Aberdeen Proving Ground
Location: Edgewood, MD, Region 3
Site Type: Superfund, final NPL
Description: The Edgewood area consists of 13,000 acres formerly used for development and testing of chemical agent munitions since 1917. Since that time, toxic materials including napalm and white phosphorus have also been tested, stored, and disposed on site. On-site buildings, water, and most soil is considered contaminated. Ground-water contaminants include metals, VOCs, and degradation products of chemical warfare agents. Soil contaminants include metals, VOCs, PCBs, and unexploded ordnance. Surface water (rivers, streams, and wetlands) is contaminated with metals, pesticides, phosphorus, and VOCs. Direct contact with, or ingestion of, ground water, surface water, soil, or sediment poses human health risks. The site was added to the NPL in 1990 and is a fund-lead site.
Remediation Strategy: On-site remedial activities include initial removal actions and fifteen long-term remedial phases. Removals included a leaking underground storage tank, surface wastes, and contaminated soils. Other cleanup actions include landfill caps, P&T systems, erosion control, and phytoremediation. At the Old O-field Chemical Munition Landfill (where solar power is used), remedial actions include removal of contaminated soil, hydraulic containment of ground water, and an extraction and chemical treatment (P&T) system. Threat of fire and explosion from landfill contents is controlled with a monitored permeable cap and a system to soak the landfill. Continuous automated biomonitoring is used to detect contaminant concentrations in treatment effluent, ensuring that it is not toxic to fish.
Alternative Energy Use: At the O-Field location, a solar panel system is used to provide power for the biomonitoring system to collect data (water levels in selected wells) for input to the SCADA information system. The PV system consists of 12 panels, each measuring 3 feet by 3 feet. It is estimated that the system saved tens of thousand of dollars in capital costs by avoiding installation of underground electrical wiring. Excavation would have been expensive and dangerous due to the unexploded ordnance found on site.
Site Contacts:

- Frank Vavra, RPM, U.S. EPA Region 3, vavra.frank@epa.gov, 215-814-3221

Site Specific Resources:

- U.S. EPA Superfund Site Progress Profile, Aberdeen Proving Ground (Edgewood Area). http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=0300421

Site Name: Altus Air Force Base
Location: Altus, OK, Region 6
Site Type: RCRA
Description: Altus AFB consists of 2,500 acres in the City of Altus, in Jackson County in southwestern Oklahoma. In 1942, the site began operation as a flight training base. In 1968, Military Airlift Command took control of the site and began training operations for the C-5A transport aircraft. Since that time, operations include training aircraft crews for the Strategic Air Command. Activities on site have included equipment cleaning, aircraft cleaning, and fire training. Releases of cleaning solutions, solvents, oil, grease, and JP-4 fuel have left associated contamination of ground water with TCE, 1,2-dichloroethane (1,2-DCA), perchloroethene (PCE), carbon tetrachloride, benzene, xylene, and toluene. Contamination in ground water is located in fractured clay and weathered shale. Hotspot concentrations of TCE were 19mg/L and the plume extended 1,100 yards downgradient of the landfill.
Remediation Strategy: Since late 2003, a pilot-scale, 10,000 cubic-foot bioreactor has been in use to address the TCE contamination. Ground water is pumped through the bioreactor and recharged to the aquifer following treatment. The bioreactor generates high carbon leachate as the ground water flows through the system, enhancing biodegradation of TCE through reductive dechlorination. The system has generated and added 1,3000 cubic meters per year of organic carbon-enriched leachate into the aquifer, reduced TCE concentrations in the bioreactor by 98%, and reduced plume toxicity in hotspots between the bioreactor cell and extraction trench by 90-97%. The bioreactor was installed in a 30-foot by 30-foot excavation, 11 feet below ground surface, immediately upgradient of the contaminant hotspot wells. The extraction trench is 2 feet wide and 30 feet long, extending 18 feet below ground surface. The TCE degradation is monitored with a system of 18 wells.
Alternative Energy Use: The base's remote location in the southwest corner of Oklahoma, where it receives average solar radiation of 4-5 $kWh/m^2/day$, makes it a prime candidate for the use of solar power. The ground water is pumped into and recirculated through the bioreactor with a 3-inch diameter submersible solar powered pump in the extraction/collection trench. The pump produces 2-3 gallons per minute when solar energy is available, but does not operate during low sunlight hours. The pump produces an average of 928 gallons per day. The PV array used to generate electricity for the pump consists of four single crystal silicon panels, mounted in series on a single frame facing due south and angled for optimal sun exposure. Each panel can deliver 50 watts to the pump. The PV system has an estimated lifespan of 20-30 years. Energy cost savings are estimated at less than $1,000 per year, but savings were also achieved by not building the power lines required to connect to the local utility grid.

Site Contacts:

- Nancy Fagan, RCRA Lead, U.S. EPA Region 6, fagan.nancy@epa.gov

Site Specific Resources:

- Technology News and Trends. May 2007. *Solar Power Recirculates Contaminated Ground Water in Low-Energy Bioreactor.*

Site Name: Apache Powder Company
Location: St. David, AZ, Region 9
Site Type: Superfund, final NPL
Description: The Apache Powder Company Site comprises 945 acres currently owned by Apache Nitrogen Products, Inc. formerly the Apache Powder Company, and is adjacent to the San Pedro River. Approximately 1,100 people rely on wells within 3 miles of the site for drinking water. The site has been in operation since 1922, producing industrial chemicals and explosives. The facility currently produces nitric acid, solid and liquid ammonium nitrate, blasting agents, nitrogenous fertilizer solutions, and explosives. Solid and liquid wastes have been disposed on-site, including direct flow of waste-water into the San Pedro River (until 1971). After 1971, waste-water was directed into unlined evaporation ponds on site, causing continual contamination of the perched ground water. Drums containing dinitrotoluene (DNT) were also disposed in a concentrated area during the 1950s and 1960s.

Contaminants identified on site consist of high concentrations of heavy metals in the ponds; arsenic, fluoride and nitrate in the perched groundwater; DNT in the drum disposal area; and nitrate in shallow wells, including a domestic drinking well with 470mg/L nitrate. The primary exposure path for the contaminants is direct ingestion of contaminated ground water.

Remediation Strategy: The perched ground-water zone was pumped and treated by forced evaporation (brine concentrator). Additionally, waste-water from the facility was also treated. The brine concentrator was completed in 1995. In 1998, it was determined that perchlorate was also a contaminant of concern (though hydraulically contained), and monitored natural attenuation was added to the record of decision (ROD) for treatment of this contaminant. The shallow aquifer was pumped and treated with the use of constructed wetlands. The wetland system covers 4.5 acres, treats 150gpm and was completed in 1997, saving over $15 million. The treated water is then pumped back into the aquifer. A total of 262 110-gallon drums have been removed and 45 cubic yards of explosives-contaminated soil were excavated, treated, and disposed off-site. A low permeability clay cap was constructed over the remaining contaminated soil to prevent infiltration and contamination of rainwater.

Alternative Energy Use: Solar power is used on site to power a pump that recirculates water through the wetlands when the water cannot be discharged to the aquifer. It consists of twelve Kyocera KC-120 PV panels with a 1,440-watt total capacity and one Suncentric 7632 centrifugal pump. The system is capable of pumping 5 gallons per minute through 100 feet of 2-inch fire hose with an elevation rise of about 10 feet. The system is only used when sunlight is available and the system is unable to discharge water from the wetlands into the aquifer (when water exceeds nitrate discharge limit of 30 parts per million (ppm)).

Site Contacts:

- Andria Benner, RPM, U.S. EPA Region 9, benner.andria@epa.gov, 415-972-3189
- Greg Hall, Apache Nitrogen Products, Inc., GHall@apachenitro.com

Site Specific Resources:

- U.S. EPA Region 9. *Five-Year Review of Soils and Groundwater Cleanup Actions*. February 2007.
- U.S. EPA Region 9 Superfund Fact Sheet. Apache Powder Company. http://yosemite.epa.gov/r9/sfund/r9sfdocw.nsf/4b229bb0820cb8b888256f0000092946/510f2916dad8646e88257007005e9402!OpenDocument#descr
- EPA Superfund Record of Decision, Apache Powder Company. 30 September 1994.

Site Name: BP Paulsboro
Location: Paulsboro, NJ, Region 2
Site Type: NJDEP ISRA
Description: The Paulsboro site, adjacent to the Delaware River, is a former BP petroleum and specialty chemical storage facility. It closed in 1996 and is currently inactive. The initial phase of cleanup began in 1996 with the demolition of 30 tanks and removal of 20 miles of underground piping. In 2003-2004, an additional 60 tanks were demolished, and all remaining underground piping was removed. Contaminants on site include refined petroleum products (i.e., gasoline, diesel, jet fuel, kerosene, and fuel oils) and chemicals including chlorinated compounds such as chlorobenzene, carbon tetrachloride, chloroform, and 1,2-DCA. The site is being cleaned up by BP under the New Jersey Department of Environmental Protection's (NJDEP) Industrial Site Recovery Act (ISRA). BP is supporting the Borough of Paulsboro and the South Jersey Port Corporation in redeveloping the former petroleum and chemical storage site into a port. The project is currently in the design and permitting phase, and expected to begin construction soon. The site serves as an ideal location for a port with access to roads, railways, and the Delaware River. This redevelopment will also create jobs and revenue for the local area.
Remediation Strategy: The current active remediation efforts consist of two SVE systems (one with air sparging), a ground-water P&T system, and an LNAPL (light non-aqueous phase liquid) skimming system. One SVE system operates at 2,500 standard cubic feet per minute (scfm) and covers 9-10 acres; the second operates at 1,500 scfm and covers approximately 5 acres. The P&T system includes six recovery wells pumping an average of 300 gallons per minute into a biologically activated carbon ground-water treatment system. The LNAPL recovery has been ongoing since the early 1980s, but operation has dwindled as most of this product has been removed. The wells originally used for removal of LNAPL from the surface of the water table now serve as a containment system for the ground-water contamination.
Alternative Energy Use: In April 2003, BP opened a 275-kW solar field, the largest on the east coast, on the Paulsboro site, generating approximately 350,000 kWh annually with an array of 5,880 panels. An estimated 20-25 percent of the electricity needed to power the P&T system (including pump motors, aerators, and blowers) is provided by the solar field. The use of this solar power system is expected to reduce CO_2 emissions by 571,000 pounds per year, SO_2 by 1,600 pounds per year, and nitrogen oxide by 1,100 pounds per year.
Site Contacts:

- Sasa Jazic, BP, sasa.jazic@bp.com, 630-836-5114
- Iain Bryant, Sovereign Consulting, Inc., ibryant@sovcon.com, 609-259-8200

Site Specific Resources:

- BP Global Press Release. BP *Builds, Operates Largest Solar Power System On East Coast*. 22 April 2003. http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=2001546
- U.S. DOE Energy Efficiency and Renewable Energy. *EERE Network News*. 30 April 2003. http://www.eere.energy.gov/news/archive.cfm/pubDate=%7Bd%20'2003-04-30'%7D

Site Name: Crozet Township Orchard Site
Location: Crozet Township, VA, Region 3
Site Type: Removal action
Description: The Crozet Township site is located west of the town of Crozet, Virginia. The site includes a former orchard area that was used during the 1940s and 1950s, during which time various pesticides (4,4'-DDT, 4,4'-DDD and 4,4'-DDE) and arsenic compounds were applied. Use of the organochloride pesticides found on site has been illegal in the United States since 1972. These pesticides have been linked to liver and kidney damage and are probable human carcinogens; arsenic is a known human carcinogen. A total of 33 properties were sampled by EPA Region 3's Site Assessment Section of the Superfund Removal Branch in 2002, and two residential properties required removal actions to prevent human exposure to the contaminants. Ground-water wells also were sampled, but no contaminants were found above background levels. Samples from one of the heavily contaminated residences (in Area One) contained arsenic at levels ranging from 50.4 ppm to 103 ppm, lead at a maximum level of 431 ppm, and pesticides at levels above 3,400 ppb (well above unaffected properties pesticide levels of 300-400 ppb). At the second residence of concern (in Area Two) arsenic existed at levels up to 111 ppm and lead at levels up to 594 ppm, but high concentrations of pesticides were not found.
Remediation Strategy: The first residential property (Area One) was excavated in November 2005. The second property has not yet been excavated. An estimated 10 additional residential properties will be excavated under the removal action. For residential properties where soil arsenic concentrations are above 58 ppm, the top six inches of soil is removed until background levels are achieved, a two-foot depth is reached, or the clay pan is reached. Soils containing pesticides at concentrations above 190 ppm that are commingled with arsenic above 58 ppm will also be excavated. All excavated soil is disposed off site according to CERCLA standards. Additionally, properties will be backfilled with new soil and revegetated with native species. In the case that excavation in any area is not feasible, phytoremediation will be used for the removal of arsenic. This will be the case if (1) there is limited physical access to the area, (2) potential exists for erosion problems, or (3) the area is heavily forested. These criteria apply to 27 of the 30 plots on the property. For the phytoremediation, arsenic absorbing ferns will be planted and maintained for the growing season, after which they will be removed and disposed off-site. The soil will be tested and ferns replanted for three growing seasons, aiming to reduce arsenic concentrations below the risk-based removal action level of 58 ppm.
Alternative Energy Use: The irrigation for the arsenic absorbing ferns is run by two systems. The first uses a spring at the top of the hill that feeds into a 4,000-gallon tank and delivers gravity-fed, drip irrigation to the ferns. This system services 17 of the plots requiring irrigation. The second system uses a solar-powered, low-flow pump to extract water from the bottom of the hill to the storage tank that feeds the gravity-fed, drip irrigation system. The system consists of three 130-watt panels (total 390-watt total capacity) connected to a small pump, which withdraws approximately 25 feet of head. The solar-powered pump feeds the irrigation system for seven of the plots.

Site Contacts:

- Myles Bartos, OSC, U.S. EPA Region 3 Removal Response Section, bartos.myles@epa.gov, 215-814-3342

Site Specific Resources:

- Bartos, Myles, OSC, U.S. EPA Region 3 Action Memorandum
- U.S. EPA Site Profile. http://epaosc.net/site_profile.asp?site_id=2891

Site Name: Lawrence Livermore National Laboratory (Site 300)
Location: Eastern Altamont Hills, near Livermore, CA, Region 9
Site Type: Superfund, final NPL (DOE federal facility)
Description: The Lawrence Livermore National Laboratory is an 11-square-mile facility operated by the University of California for DOE, as a high-explosives and materials testing site for nuclear weapons research initiated in 1955. Ground water is provided as drinking water to 350 workers on the site as well as to local ranch houses and a state fire station. Ground-water contaminants, released from various on-site activities, include solvents, VOCs, tritium, uranium-238, highly explosive compounds (HMX, RDX), nitrate, and perchlorate. Sources of contamination include spills, leaking pipes, leaching from underground landfills and pits, high-explosives testing and disposal of waste liquids in lagoons and dry wells.
Remediation Strategy: Currently, a P&T system is operating to treat contaminated ground water at four locations (General Services Administration (GSA), Building 834, HE Process Area, and Building 832 Canyon). SVE systems are in place to treat VOCs in the vadose zone at three of the ground-water treatment locations (GSA, Building 834, and Building 832 Canyon). Perchlorate has been examined with treatability studies, and is typically removed by ion exchange and/or bioreactors. Based on the second five-year review, released in December 2006, cleanup standards have been reached in the Eastern GSA ground water and it was proposed that the ground-water extraction and treatment system be shut off and the ground water monitored for increasing levels of VOCs. It was recommended that SVE and monitoring systems in the Central GSA continue operation.
Alternative Energy Use: Solar power is used on-site to pump water through four GAC systems. The systems were all installed between June 1999 and September 2005. The low-flow systems pump ground water at about 5 gallons per minute from depths of 75-100 feet. Each system has a capacity of 800 watts (for a total of 3.2 kW) and costs about $2,000. These four systems are located at Site 300 and one additional unit is located at the LLNL Main Site, located 15 miles west of Site 300. These systems are not grid-connected, but they are equipped with a battery to store excess power to allow for some operation during non-daylight hours.
Site Contacts:

- Kathy Setian, RPM, U.S. EPA, Region 9, setian.kathy@epa.gov, 415-972-3180
- Ed Folsom, Lawrence Livermore National Laboratory, folsom1@llnl.gov

Site Specific Resources:

- U.S. EPA Superfund Fact Sheet, Lawrence Livermore National Laboratory (Site 300), http://yosemite.epa.gov/r9/sfund/r9sfdocw.nsf/4b229bb0820cb8b888256f0000092946/d83824759d4ae31d88257007005e9408!OpenDocument
- Dibley, V., J. Valett, and L. Ferry. *Final Five-Year Review Report for the General Services Operable Unit at Lawrence Livermore National Laboratory Site 300*. U.S. DOE. December 2006.

Site Name: Pemaco Maywood
Location: Maywood, CA, Region 9
Site Type: Superfund, final NPL
Description: The Pemaco site is a former chemical mixing facility in Maywood, CA, which began operations in the 1940s. The site was purchased by the LUX Chemical Company in 1988 and operations ceased in 1991. Hazardous substances used at the facility included: chlorinated solvents, aromatic solvents, and flammable liquids. In 1993, a fire destroyed the facility, burning the warehouse to the ground, leaving six 55-gallon drums, several aboveground storage tanks, and 31 undamaged USTs. Following the fire, the EPA secured the site, verified the storage tanks were empty, and removed a few of the 55-gallon drums. Records indicate that the tanks had contained a variety of chemicals (methanol, ethanol, xylene, propylene glycol, kerosene, toluene, unleaded gasoline, and other organic compounds). EPA determined that on-site soil and ground water were contaminated with VOCs including: PCE, TCE, trichloroethane (TCA), DCA, and vinyl chloride.
Remediation Strategy: Site cleanup began in 1997 with the removal of 29 underground storage tanks and several aboveground storage tanks. The entire facility (piping, asphalt, concrete, and burned-out warehouse) was demolished. The ROD was signed in 2005 and called for the following remedies: (1) a soil cover and revegetation (for surface and near surface soils), (2) high-vacuum dual phase extraction (HVDPE) system using ultraviolet oxidation (UV/Ox) and GAC for water treatment, and flameless thermal oxidation (FTO) for vapor treatment (for upper vadose soils and perched ground water), and (3) electrical resistance heating (ERH) with vapor extraction, vacuum enhanced ground-water extraction, ground-water P&T, and monitored natural attenuation using UV/Ox for water treatment, and FTO and GAC for vapor treatment. EPA also monitors air quality and vapors for elevated contaminant levels. Construction of the remedies began in August 2005. Pemaco is a fund-lead site with all cleanup costs paid by the federal government.
Alternative Energy Use: The Pemaco site uses a 3- kW PV system to provide power to backup batteries. In the case of an electrical emergency, the batteries would provide power to the computers that operate the treatment plant. The PV panels were installed and operational as of June 29, 2007, and power was being directed directly back into the utility grid. The PV system will produce an estimated 375 kW hours per month (4,506 kWh/year) and will reduce emissions of CO_2 by 4,311 pounds per year, nitrogen oxides by 4 pounds per year, and SO_2 3 pounds per year.
Site Contacts:

- RoseMarie Caraway, RPM, U.S. EPA Region 9, caraway.rosemarie@epa.gov, 415-972-3158
- Maggie Witt, US EPA Region 9, witt.maggie@epa.gov, 415-972-3370

Site Specific Resources

- U.S. EPA Superfund Site Progress Profile, Pemaco Maywood, http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=0904950

Site Name: Raytheon Aircraft Company
Location: Boulder, CO, Region 8
Site Type: RCRA
Description: Raytheon Aircraft Company, previously known as Beech Aircraft, owned and operated a 1,500-acre facility near Boulder, Colorado. The site was used for the manufacture of missile and aerospace products and the operation of fueling services for missiles and military training targets. The manufacturing operations were suspended in 1987 and fueling operations ended in 1999. All of the facility's operations took place on the portion of property on the west side of U.S. Highway 36. Raytheon sold 1.237 acres east of the highway to Boulder Open Space and a large portion to Santa Fe Land Company, who later sold 73 acres to Boulder Open Space. Raytheon currently owns only 38 acres on the west side of the highway, where cleanup activity is centered. Boulder Open Space and Santa Fe Land Company currently own and operate the remaining property of the former facility. Sources of contamination include an earthen-lined pool formerly used for waste liquids from the manufacturing processes ("Impoundment Area"), groundwater seepage into the adjacent Beech Open Space, and former on site fueling operations. Contaminants of concern include chromium, TCE, PCE, other VOCs, and nitrosodimethylamine (NDMA, a byproduct of hydrazine).
Remediation Strategy: Wastes at the impoundment area were removed and disposed at an offsite facility. To treat VOC-contaminated ground-water seepage to the Beech Open Space area on the other side of the highway, Raytheon installed ground-water extraction wells and a treatment facility in 1995 and an SVE system in 1997. Seepage from the Raytheon property is still being treated. In the Target/Missile Fueling Area, Raytheon installed 15 wells to investigate soil and water contamination. Residual concentrations of VOCs and NDMA were not found to be a threat to ground water due to hydraulic conditions; however, cleanup strategies (biological degradation and chemical oxidation) are being investigated for this area. A (phase 1) RCRA facility investigation (RFI) was submitted to EPA in October 2003 and a phase 2 RFI is currently being produced. Following submission of the phase 2 RFI, a corrective measures workplan will be submitted, detailing the completion of cleanup activities.
Alternative Energy Use: Raytheon has recently proposed the use of solar-powered ground-water remediation monitoring systems. Information regarding the use of this technology is currently under review. Publication of a RCRA corrective action "statement of bases" containing this information is expected later this year.
Site Contacts:

- Noreen Okubo, RPM, U.S. EPA Region 8, okubo.noreen@epa.gov, 303-312-6646

Site Specific Resources

- U.S. EPA Region 8, RCRA Facilities Fact Sheets, Raytheon Aircraft Company (RAC), http://www.epa.gov/region8/land_waste/rcra/fact/raytheon.html

Site Name: Savannah River Site
Location: Aiken, SC, Region 4
Site Type: Superfund, final NPL, (DOE federal facility)
Description: SRS is a secured government facility, located adjacent to the Savannah River, southeast of Augusta, Georgia. It encompasses 310 square miles in both Aiken and Barnwell Counties in South Carolina. The site was constructed in the 1950s to produce materials for nuclear weapon fabrication for U.S. defense programs (principally tritium and plutonium-239). On-site facilities include five nuclear reactors, two chemical separations plants, a heavy-water extraction plant, a nuclear fuel and target-fabrication facility, and waste-management facilities. Nuclear-materials fabrication activities were discontinued in 1988. Prior to that time, chemical and radioactive wastes were treated, stored, and disposed at SRS, resulting in soil and ground-water contamination. The cleanup efforts are being dealt with by EPA, South Caroline Department of Health and Environmental Control (SCDHEC), and DOE under a RCRA permit and CERCLA 120 federal facility agreement.
Remediation Strategy: Since 1981, a total of 515 inactive waste sites have been identified at SRS (323 of which have been closed) including basins, pits, piles, burial grounds, landfills, tanks, and associated ground-water contamination. Billions of gallons of waste-water have been treated and about one million pounds of chlorinated solvents have been removed. Numerous treatment operations take place on-site, including several energy-efficient and alternative-energy technologies: bioremediation, monitored natural attenuation (MNA), barometric pumping (PSVE), solar-powered MicroBlowers, and dynamic underground steam stripping. Cleanup activities have been underway since 1985 (with a RCRA permit), with continued joint RCRA/CERCLA cleanup efforts under the federal facility agreement.
Alternative Energy Use: The principle use of alternative energy at SRS is with the solar-powered MicroBlowers (low-flow, low-power, active SVE devices). These devices are used in the A Area Burning/Rubble Pits (731-A/1A) and Rubble Pit (731-2A) Operable Unit (OU). The system comprises a 12- or 24-volt DC vacuum blower connected to a wellhead for extracting or injecting gasses into the vadose zone. These systems are powered by PV but can also be powered with small wind turbines. Currently, ten MicroBlower systems are in operation at SRS, each with a removal rate of 0.1 to several pounds of VOCs per week. When solar power is not available, PSVE is used to extract soil gasses. Additionally, solar energy is used to power a remote monitoring system (RMS) for MNA remediation at two ground-water wells. The RMS consists of wireless data collection, analysis, transmission, and data management, and is intended to remotely detect halogenated VOC levels in the contaminated ground water.
Site Contacts:

- Brian Riha, Savannah River National Laboratory, brian.riha@srnl.doe.gov, 803-725-5948
- Brian Looney, Ph.D., Savannah River National Laboratory, brian02.looney@srnl.doe.gov, 803-725-3692

Site Specific Resources:

- U.S. EPA Superfund Site Progress Profile, Savannah River Site (USDOE) http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=0403485

- U.S. DOE Savannah River Site, *Soil and Groundwater Closure Projects Technology Descriptions, Revision 7.1*. January 2007
- Technology News and Trends. May 2007. *DOE Uses No/Low Energy Approaches for Long Term Remediation*.

Site Name: F.E. Warren Air Force Base
Location: Cheyenne, WY, Region 8
Site Type: Superfund final NPL (DOD federal facility)
Description: The F.E. Warren AFB is located west of the city of Cheyenne and comprises approximately 6,000 acres. Originally a U.S. Army outpost in 1867, the site was named Fort D.A. Russell until 1930 when the name was changed to F.E. Warren and was used as a training facility during World War II. In 1947, the site was transferred to the U.S. Air Force; in 1958, the site became a Strategic Air Command site. The site also served as an operations center for the Atlas intercontinental ballistic missile (ICBM), Minuteman I and III and for the Peacekeeper ICBMs. Contamination was identified in ten OUs on the site including 13 landfills, two fire-protection training areas, six spill sites, a firing range, a battery-acid disposal site, an open-burn/detonation area, and site-wide ground-water contamination. The principle contaminants of concern are solvents and fuels in both the soil and ground water. Ground-water migration and seepage to the east of the site also caused ground-water contamination in local residential areas.
Remediation Strategy: Municipal water has been supplied to residents affected by contaminated ground-water seepage from the site. Landfill cleanup strategies vary by location and include: excavation and disposal of non-hazardous waste at an off-site landfill, construction of landfill caps and gas venting systems, and LFG monitoring. At one spill site, a 600foot-long wall of granular iron was constructed beneath the water table, employing a reductive biological process to degrade VOCs. Additionally, the ROD specified P&T systems for two OUs contaminated with TCE. Subsurface chemical oxidation or bioaugmentation with MNA components is selected for the remaining ground-water OUs contaminated with TCE. Most remedies have been selected as of 2007 with firing ranges and some smaller units still under investigation.
Alternative Energy Use: F.E. Warren Air Force Base has been utilizing wind power since 2005, with the operation of two 660-kW wind turbines. It is estimated that the turbines will generate 4.4 million kW hours and save 4,866 tons of CO_2 emissions per year. The wind farm is expected to save over 3 million dollars in energy costs over the next 20 years. At this time, only a small portion of the energy used for remediation and monitoring equipment can be attributed to the use of wind power. Additional wind mills may be added if cost savings are demonstrated.
Site Contacts:

- Jeff Mashburn, RPM, U.S. EPA Region 8, mashburn.jeff@epa.gov, 303-312-6665.
- Rob Stites, U.S. EPA Region 8, stites.rob@epa.gov

Site Specific Resources

- American Wind Energy Association. *Wyoming Wind Energy Development*. http://www.awea.org/projects/wyoming.html
- Air Force Center for Environmental Excellence. Center Views. *First Air Force wind farm erected at Warren AFB.* http://www.afcee.brooks.af.mil/ms/msp/center/Vol11No3/10.asp
- EPA Superfund Site Progress Profile, F.E. Warren Air Force Base, http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=0800017

Site Name: Former Nebraska Ordnance Plant
Location: Mead, NE, Region 7
Site Type: Superfund, final NPL
Description: The Nebraska Army Ordnance Plant is a Formerly Used Defense Site (FUDS) and the U.S. Department of Defense (DOD) (specifically the U.S. Army Corps of Engineers (USACE)) is the lead agency at the site. It was a 17,000-acre munitions production plant that operated during World War II and the Korean War. It operated from 1942 to 1956; past uses included loading, assembling, and packing of ordnances at four load-line facilities. The Army also used the site for munitions storage and production of ammonium nitrate (an oxidizing agent). Following the Army's operations on the site, the Air Force built and maintained three Atlas missile silos from 1959 to 1964. The University of Nebraska now owns the major production area of the plant, totaling about 9,000 acres, for their Agriculture Research and Development Center. The remaining property is owned by the Nebraska National Guard and several individuals and corporations. The University has disposed of low-level radioactive waste, other chemicals, and solid wastes on-site, and is in the process of investigating and remediating those wastes. Ground water at and near the site is used for both public and private water supplies, and is also used for crop irrigation and livestock watering. Contaminants include VOCs (primarily TCE) and explosives, as well as possible unexploded ordnance.
Remediation Strategy: To clean up soil contaminated with explosives, the Army excavated and incinerated 16,500 cubic yards of soil. This action was completed in 1998 under a ROD dated 29 August 1995. To clean up ground water contaminated with TCE and explosives, a P&T remedy was selected (ROD dated 7 April 1997). The ground-water remedy calls for hydraulic containment of ground water exceeding cleanup criteria, along with focused extraction and treatment of areas with highly contaminated ground water. The treatment includes GAC adsorption, advanced oxidation processes, and air stripping. The treated ground water is discharged to surface water, and during the irrigation season is beneficially reused for agricultural purposes. GCWs may be used for "focused extraction" and treating the highly contaminated groundwater. Two GCWs have been in operation at the site for several years as part of a pilot study. One of the GCWs is powered by a wind turbine system.
Alternative Energy Use: Funds from the U. S. Army Corps of Engineers, EPA, and the Missouri Research Board to the University of Missouri-Rolla provided resources for the pilot-scale study of the use of a 10-kW wind turbine to power one GCW, operating at a flow rate 50gpm. The GCW is equipped with air strippers used to treat TCE-contaminated ground water. The study was funded for a period beginning October 2003 through August 2006. The wind turbine operated under grid inter-tie mode, in which both utility-supplied power and wind turbine power could be used for system operations. It was estimated that the wind turbine generates 817 kWh per month and that the treatment system uses 767 kWh per month. Wind turbine use saved an estimated total of 17,882 lbs of CO_2 emissions over a period of 19 months. The most recent data (January 2005) shows a decrease in TCE concentrations after treatment from 648 micrograms per liter to 42 micrograms per liter, a reduction of over 90%. Data collection is ongoing; however, funds are not available to continue site research.

Site Contacts:

- Scott Marquess, RPM, U.S. EPA Region 7, marquess.scott@epa.gov
- Dave Drake, RPM, U.S. EPA Region 7, drake.dave@epa.gov
- Curt Elmore, Ph.D., P.E., Assistant Professor of Geological Engineering, University of Missouri-Rolla, elmoreac@umr.edu, 573-341-6784
- Garth Anderson, P.E., USACE - Kansas City District, 816-389-3255, h.garth.anderson@usace.army.mil

Site Specific Resources:

- U.S. EPA Region 7 Fact Sheet: Nebraska Army Ordnance Plant, http://www.epa.gov/region07/cleanup/npl_files/ne6211890011.pdf 17 November 2005.
- Elmore, Curt and Ron Gallagher. *Groundwater Remediation Powered by a Renewable Energy Source*. University of Missouri-Rolla, Geological Engineering. September 2005.
- U.S. EPA Superfund Site Progress Profile, Nebraska Ordnance Plant (Former) http://cfpub.epa.gov/supercpad/cursites/csitinfo.cfm?id=0702031
- Elmore, A.C., R. Gallagher, & K.D. Drake. 2004. *Using wind to power a groundwater circulation well - preliminary results*. Remediation.14(4), 49-65.
- Elmore, A.C. 2007. *Economic and environmental benefits of using a wind turbine to power a groundwater remediation system*. Proceedings of the ASCE World Environmental and Water Resources Congress, Tampa, Florida. May 15-19.
- Technology News and Trends. September 2004. *Wind Turbine Powers Ground-Water Circulation Well*.

Site Name: St. Croix Alumina Site
Location: Kingshill, St. Croix, U.S. Virgin Islands, Region 2
Site Type: RCRA 7003 administrative order on consent
Description: The St. Croix Alumina (SCA) site is a former bauxite refinery for aluminum processing which operated from the mid 1960s until 2002. The site is located immediately west of the HOVENSA (formerly Hess Oil Virgin Islands Corporation, HOVIC) oil refinery. EPA identified an oil plume underneath the SCA site in 1994, and believed it to be a result of releases from the adjacent HOVENSA refinery facility. After three years of EPA-mandated investigations, chromatographic analysis of ground-water samples indicated that the contamination at SCA resulted from commingled petroleum products (diesel, gasoline, and No. 6 fuel oil) from both sites, estimated to have been released between 1978 and 1991. In May 2001, a RCRA Section 7003 administrative order on consent (AOC) was activated between EPA and seven past and present owners of the SCA and HOVENSA facilities. The AOC requires cleanup of both the large plume floating on the Kingshill aquifer and the dissolved-phase petroleum hydrocarbons in the ground water. The Kingshill aquifer is the primary drinking water aquifer in St. Croix, but is not used for drinking water down gradient of the SCA site.
Remediation Strategy: The oil recovery system, initiated in 2002, operates with the use of WDTCs powered by and positioned on top of four on-site windmills. The compressed air produced by the system drives the ground-water pumps in six “total fluid” recovery wells. The recovered fluid is sent to the adjacent HOVENSA refinery where the oil is separated from the water and recycled into the refinery. An additional nine monitoring wells are located around the perimeter of the oil plume to monitor migration of contaminants. In November 2004 an additional recovery well was added in the western portion of the plume. As of December 31, 2006 a total of 228,018 gallons of free petroleum product has been recovered. The average recovery rate for the period from July 1 to December 31, 2006, was 63.34 gallons of free product per day. As of January 30, 2007, the estimated remaining free product at the site was 908,376 gallons. To that point, 20% of the estimated total free product had been removed. In 2007, an additional three recovery wells were added for a total of nine recovery wells.
Alternative Energy Use: The four windmills consist of 8’ 8” diameter blades that begin generating power with wind speeds of 4 mph. Protective measures are also taken to ensure the safety of the unit; when winds reach 30 mph, the blades will roll up and turn out of the wind. The unit can also be lowered to the ground for maintenance or protection in case of a hurricane. The site is exposed to trade winds, providing a near constant source of 8-10 mph winds, making the site well suited for wind energy applications. Each windmill and WDTC operates at about 10 scfm and 45psi of operating pressure, driving hydraulic oil “skimmer” pumps. The WDTCs are still operational; however, replacements for these units are no longer available. Additionally, three PV arrays, each consisting of three PV panels, have been operational since 2003. Each panel has a capacity of 55 watts and each array has a capacity of 165 watts, for a total capacity of 495 watts. In 2007, three solar panels, each with a capacity of 110 watts, were added for a total capacity of 330 watts. Also in 2007, two MH80 wind-driven electric generators (WEGs) were added to the system. Each WEG has an output of 110 volts. The added solar panels and WEGs power “total fluid” submersible pumps that recover oil, ground water, and dissolved phase hydrocarbons.

Site Contacts:

- Tim Gordon, U.S. EPA RCRA Programs Branch, gordon.timothy@epa.gov, 212-637-4167

Site Specific Resources:

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Site Name: Operating Industries, Inc. Landfill
Location: Monterey Park, CA, Region 9
Site Type: Superfund, final NPL
Description: The site began landfill operation in 1948 under Monterey Park Disposal Company, and was purchased by Operating Industries, Inc. (OII) in the 1950s. Located 10 miles east of Los Angeles, this site is divided into two parcels by the Pomona Highway (Highway 60): The North Parcel is owned by A.H.A.S., Inc and contains about 45 acres; the South Parcel is owned by OII and contains about 145 acres. Of the 45 acres in the North Parcel, only about 10 are known to have been used as a landfill, and contain mostly construction and demolition waste (wood, glass, metal, paper, cardboard, brick, asphalt, concrete, and plastic). The South Parcel received the majority of the waste and contains residential and commercial refuse, liquid wastes, and various hazardous wastes. The facility closed operations and stopped accepting wastes in 1984. Threats in the South Parcel include organic and inorganic compounds in the air, ground water, soil, and leachate; exposure pathways include inhalation of gasses or ingestion of these media. A majority of the LFG is produced in the South Parcel by the decomposition of the organic/residential waste. Due to relatively inert nature of the waste on the North Parcel, a small amount of LFG is generated in the North Parcel. The ground water beneath and around the site contains organic and inorganic compounds.
Remediation Strategy: There are four (OUs) at the OII Site. Prior to issuing the final RODS, EPA had identified three OUs at the site: site control and monitoring (SCM); leachate management (LM); gas migration control and landfill cover (gas control and cover); and ground-water remedy.

EPA identified the first two OUs (SCM and LM) to facilitate interim remedial actions and issued two interim RODs, which were later superseded by the Final ROD. The SCM ROD was signed in July 1987 and the LM ROD was signed in November 1987. EPA identified the third OU to accelerate the final remediation for the LFG control and landfill cover. The third ROD was issued in September 1988 and amended on September 1990. Unlike the two previous interim RODs, this ROD selected a permanent remedy for the LFG control and landfill cover. On September 30, 1996, EPA issued the final ROD for the site which selects a permanent remedy for ground-water contamination, as well as for the matters previously addressed by the two interim RODs.

The selected remedy in the final ROD (September 1996) includes control of landfill liquids around the perimeter of the facility and natural attenuation and monitoring of the ground water away from the perimeter, as well as long-term monitoring, operation, and maintenance of the remedy. Amendments to the ROD called for the addition of new gas-extraction wells, gas piping, additional gas-destruction capacity, and monitoring facilities. Also added was a landfill-cover system to prevent the surface migration of gas and reduce odor, dust, infiltration of water and oxygen, and erosion. Surface-water management was also incorporated into the system. These remedies were completed on the South Parcel in 2000. The North Parcel does not generate large quantities of landfill gas. A final North Parcel cover and passive LFG control system are scheduled to begin construction in 2007/2008, allowing for future redevelopment.
Alternative Energy Use: Six microturbines were installed on the North Parcel as part of the LFG collection system in 2002, converting LFG to electric power. All emissions from the microturbines are collected and returned to the gas treatment system to ensure

removal of all contaminants. The microturbines save up to $400,000 per year, and generate enough power to supply about 70% of the landfill's energy needs. Each microturbine has a generating capacity of 70 kW, for a total of 420 kW. They operate approximately 70% of the time and provide power for remedial systems and site O&M.

Site Contacts:

- Shiann-Jang Chern, Alternate Project Coordinator, U.S. EPA Region 9, chern.shiann-jang@epa.gov, 415-972-3268
- Pankaj Arora, Project Coordinator, U.S. EPA Region 9, arora.pankaj@epa.gov, 415-972-3040

Site Specific Resources:

- U.S. EPA Superfund Site Progress Profile, Operating Industries, Inc. Landfill, http://yosemite.epa.gov/r9/sfund/r9sfdocw.nsf/ViewByEPAID/cat080012024?OpenDocument

Site Name: Grove Brownfield
Location: Austin, TX, EPA Region 6
Site Type: Brownfield
Description: The Grove Landfill Brownfield Site is a 9.8-acre property in Austin, Texas. 3.6 acres of the site served as a legal landfill facility from 1967 to 1970, and was the site of illegal dumping for another 15 years following closure of the landfill. The City of Austin Redevelopment Office originally estimated that the site contained approximately 5,000 cubic yards of illegally dumped debris, and that it was not cost-effective for a developer to clean up and sell the property. Rhizome Collective, a nonprofit organization based in Austin, Texas, applied for an EPA brownfield cleanup grant. After cleanup the non-profit plans to build an environmental education park. All proposed cleanup and building strategies incorporated sustainable and innovative technologies. Rhizome Collective received the $200,000 grant award in November of 2004 and began the cleanup process in January of 2005.
Remediation Strategy: A pile of on-site debris measured 25 feet tall by 600 feet long, and consisted of roofing tin, wood scraps, asphalt shingles, concrete blocks, iron rebar, tires, glass, and household trash. Rebar pieces were cut with an oxygen-acetylene torch to untangle piles of debris. Collected debris was separated based on its ability to be recycled. Metal and glass were taken to local recycling facilities; wood was mulched for reuse in the redeveloped park; concrete was kept and used as fill for building infrastructure fro the park; tires were disposed by City of Austin Solid Waste Services. One barrel of unidentified petroleum based liquid was also disposed by City of Austin Solid Waste Services. In total, 680 tires, 10.1 tons and 36.5 cubic yards of trash, and 31.6 tons of recyclable metal were removed from the site, while wood and concrete were retained for future reuse. More than 1,600 volunteer hours contributed to the cleanup effort. The Texas Commission of Environmental Quality issued a certificate of completion for the cleanup on April 16, 2007.
Alternative Energy Use: Several uses of alternative energy and energy conservative technologies were employed at the Grove Brownfield Site. First, the tractor used to extract debris from the pile was powered with recycled residential vegetable oil, reducing CO_2 emissions. Second, equipment was powered on site with biofuel generators and solar panels, as there was no utility power on site. Additionally, in order to assist with the biodegradation of residual pollutants, chainsaw inoculated with fungi spore laden oil were used. Finally, floating islands were built using recovered soda bottles to create habitat for aquatic life, aiding with bioremediation of toxins in the retention pond on site.
Site Contacts:

- Dorothy Crawford, U.S. EPA Region 6 Brownfields Team, crawford.dorothy@epa.gov, 214-665-2771

Site Specific Resources

- Rhizome Collective Brownfield Cleanup, http://www.rhizomecollective.org/node/8

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