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Green Remediation Best Management Practices:
Landfill Cover Systems & Energy Production

Office of Superfund Remediation and Technology Innovation

Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outline the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) recommended in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.

Remediation at thousands of sites across the United States involves hazardous waste from former industrial landfills or waste piles, aged municipal landfills, or illegal dumps. A cover system is commonly installed at these areas as part of proper closure to serve as a surface barrier that contains the source material, reduces contaminant exposure or migration, and manages associated risk. Also known as a cap or cover, a cover system is typically used where:

- A hazardous, municipal, or co-disposal landfill was created before the 1976 enactment of, and subsequent amendments to, the Resource Conservation and Recovery Act (RCRA)
- An existing unit such as a closed impoundment has been designated as a consolidation area or a decision is made to build a new onsite landfill, and/or
- Direct contact or groundwater leaching presents a risk.

Cover systems can benefit from innovative designs that increase long-term performance while reducing maintenance needs. When properly designed and maintained, a final cover system for a closed landfill or consolidation unit can also provide significant opportunities for site reuse (typically on a restricted basis).

The environmental footprint of activities needed to install and maintain a cover system can be reduced by adhering to EPA's ***Principles for Greener Cleanups***. The core elements of a greener cleanup involve:

- Reducing total energy use and increasing the percentage of renewable energy
- Reducing air pollutants and greenhouse gas (GHG) emissions
- Reducing water use and negative impacts on water resources
- Improving materials management and waste reduction efforts, and
- Protecting ecosystem services.

Green remediation BMPs for addressing landfills focus on:

- ➢ ***Designing and installing a cover system*** through approaches such as materials life cycle assessment for conventional covers or selection of alternative caps
- ➢ ***Landfill gas recovery for beneficial use*** as a renewable source of energy
- ➢ ***Integrating landfill cover designs with reuse*** of a site for generating energy from solar or wind resources or for other beneficial use, and
- ➢ ***Maintaining and monitoring a final cover*** through streamlined operation and maintenance (O&M) activities and automated equipment.

Landfills built to contain hazardous wastes are governed by Subtitle C of RCRA (40 CFR 264.300), while those constructed for non-hazardous waste such as municipal solid waste (MSW) are covered by RCRA Subtitle D (40 CFR 258). In addition to RCRA requirements, closure and capping of a landfill or former waste area can be subject to requirements of the Clean Air Act, Clean Water Act, and other federal, state, or local regulations. In cleanup programs such as Superfund, these regulations can be applied to parts of a remedy as applicable or relevant and appropriate requirements (ARARs).

Designing and Installing a Cover System

A Subtitle C or D ***conventional cover system***, also known as a barrier cover, is linked to the landfill liner system. This type of cover consists of a layer of compacted soil with permeability below or equal to that of the liner or the natural soils present (or for Subtitle D, permeability no greater than 1 x 10^{-5} cm/sec). Since the liner of a Subtitle C cover system often consists of a geomembrane, its corresponding cover needs to be constructed in a fashion resulting in equivalent permeability. Other layers for drainage or gas collection or to serve as a biobarrier can be added. ***Green remediation BMPs*** for designing and installing a conventional cover system include:

- Design in ways that mimic rather than alter the site's natural setting, to improve the cover's long-term performance and protect ecosystem services[2] such as potable water, wildlife habitat, and carbon storage

- Design a cover accounting for potential effects of climate change, which could involve changes in onsite soil development or increased vulnerability to flooding
- Use uncontaminated soil or sediment from onsite excavation instead of imported soil/sediment for the cover's frost prevention and erosion control layers; similarly, uncontaminated sand, gravel, and rocks from onsite instead of offsite areas may be used for drainage
- Apply low impact development[3] strategies such as installing earthen berms to manage stormwater
- Choose geotextile fabric or drainage tubing composed of 100% recycled materials rather than virgin materials for lining, erosion control, and drainage
- Select materials with biobased content for daily activities during cover construction, including those designated for procurement by federal agencies[4]
- Use clean fuel and emission control technologies for routine field vehicles and machinery such as backhoes and bulldozers to reduce fuel consumption and emission of air pollutants such as GHGs and particulate matter,[5a] and
- Investigate onsite solar and wind resources to power equipment such as leachate pumps and flare units.

An ***alternative design*** for a landfill can be proposed in lieu of a RCRA barrier design if it demonstrates equivalent performance for criteria such as infiltration reduction and erosion resistance. Subtitle D landfill regulations also allow installation of equivalent alternative covers and innovative covers that support research. One alternative design involves covers composed of ***asphalt or concrete***. Systems based on this design are best applied to sites where minimal settlement is expected. BMPs to reduce the environmental footprint of this design include:

- Consider using asphalt rubber (containing recycled tires) where the cover system includes a layer of asphalt
- Substitute concrete with high albedo pavement, which reflects sunlight and heat away from the cover surface and may aid growth of nearby vegetation
- Consider using concrete containing a high percentage of industrial waste by-products as a substitute for cement, if tests show no contaminant leaching, and
- Use concrete wash-outs to assure proper disposal of mix water.

Another alterrnative design is an ***evapotranspiration (ET) cover system***, which prevents infiltration of water into the contained waste.[6] An ET cover relies on a thick soil layer with vegetative cover capable of storing water until it is transpired or evaporated. ET covers perform best in arid and semi-arid environments such as those found in parts of the Great Plains and western states.[7]

*A capillary barrier **ET cover** at the **Monticello Mill Tailings NPL Site** in Utah was designed to mimic the area's ecology and follow the natural progression of revegetation. Native species existing atop the cover after seven years include gray rabbitbrush and sagebrush.*

ET cover designs present two alternatives. A monolithic design uses a vegetated, relatively homogeneous, fine-grained soil layer to retain water and limit deep drainage. In contrast, a capillary barrier design consists of a fine-grained soil layer overlaying coarser material such as sand or gravel. The coarse layer forms a capillary break at the layer interface, allowing the fine-grained layer to retain more water than a monolithic cover system of equal thickness.

A capillary barrier ET cover system can be designed to enable the capillary break layer to act as a biobarrier or gas collection layer.

In addition to BMPs that apply to conventional covers, BMPs for designing and installing an ET cover include:

- Choose recycled (crushed) concrete for biobarriers or capillary breaks instead of natural rock
- Select native drought-resistant plants for the upper vegetative layer to reduce maintenance needs
- Preserve biodiversity and related ecosystem services by installing a suitable mix of native shrubs, grasses, and forbs, and
- Use nonsynthetic amendments such as compost instead of chemical fertilizers if the soil or vegetation is found to need supplementation over time.

Information on alternative landfill covers at more than 200 sites is available in EPA's alternative landfill database.[8] Additional BMPs that can apply at many landfills undergoing cover installation are described in *Green Remediation: Best Management Practices for Excavation and Surface Restoration*.[5b]

Landfill Gas Recovery for Beneficial Use

EPA encourages owners or operators of sites with landfills to use landfill gas (LFG) as a source of energy. Evaluating the options for a waste gas-to-energy system before, rather than after, waste is placed in a new landfill or consolidation unit can maximize this potential throughout the life of a landfill. Similarly, integration of the components for an LFG collection system into the design for a final cover at a closed landfill can help avoid later retrofitting and additional costs if site or administrative conditions change over time.

The capacity of LFG to provide useable energy generally depends on its proportion of methane, a potent GHG traditionally destroyed through combustion (flaring). LFG from recently closed MSW landfills with properly operated gas collection systems, for example, often contains 40-60% methane; the remainder consists primarily of carbon dioxide (CO_2), another GHG. As a landfill ages, its methane generation decreases at a rate depending on the volume and type of organic waste content and site conditions such as average rainfall. In contrast, an industrial landfill or a construction and debris landfill typically emits very little LFG throughout its life. Additional characteristics to consider when evaluating feasibility of an LFG-to-energy system include depth of the waste, impermeability of the cap and liner, and local electricity prices.

The global warming potential of methane is 21 times higher than that of CO_2.[9]

As a small facility, the ***Crow Wing County SLF*** *municipal landfill in Brainerd, MN, is not required to collect and combust its LFG. Accelerated generation of LFG after startup of the landfill's leachate collection system, however, led to voluntary installation of a 10-well LFG recovery system. With a throughput of only 30 standard cubic feet per minute (scfm), the LFG is now recovered for* ***direct use to fuel a boiler*** *that heats the facility's onsite buildings. Since 2009 installation of the LFG recovery system, the facility's natural gas consumption has decreased by nearly 70%. The County estimates a* ***$5,000 annual savings in utility costs*** *due to lower natural gas consumption and a return on the LFG recovery system investment within eight to nine years.*

With appropriate treatment, LFG can be channeled for ***direct use*** to power equipment operating on low or medium BTU gas (about 50% of the heating value of natural gas) for onsite operations. Medium BTU gas also could be piped to an adjacent facility to fuel equipment such as industrial boilers and cement kilns or to provide heating in commercial businesses such as plant nurseries. LFG can also be routed to internal combustion engines, turbines, or microturbines that ***generate electricity***. Internal combustion engines are typically the choice for LFG projects sized at 800 kW and larger, while microturbines are used for smaller projects (as little as 30 kW). Unlike most internal combustion engines, microturbines can operate with low LFG flow or methane content.[10] Most engines or turbines can be used singularly or in parallel configuration.

Points of Reference

- *LFG energy content varies but averages about 500 BTU/cubic foot.*
- *The output of one 30-kW microturbine can power a 40-hp motor.*
- *A 1-MW generator could meet the annual electricity needs of 1,070 U.S. homes.*

The ***Lowry Landfill Superfund Site*** *in Aurora, CO, occupies over 500 acres formerly used for municipal, hazardous, and industrial waste disposal. Contamination was partially addressed by constructing a conventional four foot-thick soil cover over the landfill. The landfill is located adjacent to the Denver Arapahoe Disposal Site (DADS), an active municipal landfill facility. Instead of being flared, the LFG from both sites is converted into electricity by* ***four internal combustion engines****. Since 2008, the Lowry Landfill/DADS landfill gas-to-energy plant has converted 630 million cubic feet of LFG into 3.2 MWh of electrical energy each year. The local utility distributes the generated electricity under a* ***renewable energy purchase agreement****.*

Electricity generated through these LFG recovery technologies can be used to:

- Power other landfill operations such as leachate collection and treatment systems
- Provide energy for long-term cleanup operations such as groundwater pump-and-treat systems, or
- Supplement the local utility grid through sale or credit mechanisms.

Six 70-kW microturbines replaced the flaring system used to treat LFG at the ***Operating Industries, Inc.*** *Superfund site cleanup project in Monterey Park, CA. The LFG was extracted at an average rate of 4,200 scfm, with a* ***methane content of 29-39%****. Upon turbine start-up, sufficient electricity was generated to meet approximately 70% of the 600-kWh demand made by the project's combustion blowers, thermal oxidizers, and auxiliary equipment. Over eight years of microturbine operations, the project realized cumulative net savings of $647,000.*

Selecting a suitable landfill gas-to-energy system considers the short- and long-term benefits gained by economy of scale and reductions in utility expenses.

Electricity Generation Technology	Typical LFG Flow Range (cubic feet per minute (cfm) at 50% methane)	Power Range (kW or MW)	Typical Capital Cost ($/kW)	Typical O&M Cost ($/kWh)
Internal Combustion Engine	38 - 1,140	100 kW - 3 MW	$2,000	$195
Turbine	1,300 – 2,100	800 kW - 10.5 MW	$1,400	$130
Microturbine	20 – 200	30 kW - 250 kW	$5,500	$380

Based on information in the Landfill Methane Outreach Program "Project Development Handbook"[11]

These technologies may also ***produce waste heat*** that can be captured and used to generate combined heat and power (CHP). In addition to providing heat for buildings, water, or industrial processes, CHP could produce steam (from a gas turbine) which in turn can power a steam generator to produce more electricity.

LFG can also be processed on site to remove oxygen, CO_2, nitrogen, and other trace gases to ***produce fuels*** with a high BTU content, such as pipeline-quality gas, compressed natural gas (CNG), and liquefied natural gas. An auto manufacturing plant at a former brownfield in Orion, MI, for example, relies on LFG from neighboring landfills as a substitute for natural gas in a significant portion of the plant operations.

CNG Production from LFG[11]

LFG Flow (scfm)	Production Volume (gallons of gasoline equivalent (GGE)/day)	Cost ($/GGE)
250	1,000	$1.40
500	2,000	$1.13
1,250	5,000	$0.91
2,500	10,000	$0.82
5,000	20,000	$0.68

Cleanup managers may explore these opportunities by:

- Applying EPA's Landfill Gas Energy Screening Tool to initially screen the potential for landfill methane recovery, associated cost, technical practicality, and anticipated reduction in GHG emissions[12]
- Working closely with potentially responsible parties (PRPs) and owners or operators to design and implement methane recovery projects on a voluntary basis
- Procuring technical assistance from experts experienced in LFG energy systems to evaluate feasibility at sites where initial screening indicates significant potential
- Engaging utilities or developers for sites with potential to generate "excess" electricity (beyond onsite needs) that contribute to state renewable energy portfolios
- Soliciting partners to demonstrate technologies that are emerging for electricity generation from LFG, such as Stirling engines (external combustion engines), organic Rankine cycle engines, and fuel cells,[13] and
- Using energy savings performance contracts to finance and obtain technical assistance for LFG projects undertaken by federal agencies.[14]

Information to help evaluate the options is available from EPA's Landfill Methane Outreach Program (LMOP); the program's tools include the *Landfill Gas Energy Project Development Handbook* and decision-making software.[15] Continuously updated information about state, local, utility, and selected federal incentives promoting LFG as a source of renewable energy is available from the Database of State Incentives for Renewable Energy.[16]

A system to recover LFG at the ***Grand River Landfill*** *in Grand Ledge, MI, has expanded twice since 1990 start-up to become a 4.0-MW electricity generator. The system relies on 189 horizontal and vertical wells that transfer LFG to a power plant adjacent to this active MSW landfill, which includes closed treatment cells for coal-burning ash. The plant uses five 800-kW internal combustion engines fueled by LFG averaging 1,350 scfm, with a steady* ***51% methane content****. About 5% of the generated electricity is used to operate the plant and the remainder is sold to the local utility. Six mechanical* ***windmills*** *drive pumps that remove the waste cell leachate, which is treated onsite before discharge to the sanitary sewer.*

Integrating Landfill Cover Designs with Reuse

The options for reuse activities, which in some cases involves long-term cleanup in other areas of a site, can take advantage of ***contact covers.*** These cover systems are designed to create a biobarrier against intrusion by people, animals, and in some cases vegetation. This type of cover is generally used with metal contaminants but can also be used for organic contaminants with low mobility. Depending on site-specific reuse goals, contact covers can be constructed of asphalt, concrete, or soil.

When properly designed, landfill covers can provide significant opportunities to host economic enterprises such as ***power production from solar and wind resources***. EPA, other government agencies, and developers have begun investigating the potential for reusing formerly contaminated lands and mining properties on a large-scale basis. EPA's RE-Powering America's Land initiative has tracked this potential at sites across the United States.[17]

EPA recommends that designs for solar farms atop closed and properly covered landfills consider technical aspects such as weight of ***photovoltaic (PV) or concentrated solar power*** equipment, landfill cover thickness, waste settlement, wind or snow loading, and cover maintenance requirements.[18] Project planners also need to account for potential challenges such as ongoing cleanup activities or liabilities.[19]

A ***1.48-MW solar farm*** *began operating in late 2010 above the 28-acre ET cover at "Site 7" of the* ***Box Canyon Landfill*** *at Marine Corp Base Camp Pendleton, CA. The farm comprises 225 fixed-tilt PV panels in a 28-module configuration covering six acres. Each panel is mounted on a self-ballasted, non-penetrating foundation spaced sufficiently apart from others to accommodate vegetation maintenance and other cover requirements specified in the site's record of decision. Over the first year of operation, the PV system produced over 2,425 MWh of electricity for transmission to the local utility. This resulted in an electricity savings of about $340,000, demand savings of about $95,000, and an estimated* CO_2 *offset exceeding 1,540 tons. More solar energy will be captured through solar farm expansion and* ***solar-powered ignition systems*** *for LFG vents.*

Another option is use of a ***solar geomembrane cover***, which can meet Subtitle D alternative cap requirements while converting solar energy to useable power. A solar geomembrane cover also can be integrated with a LFG recovery system to maximize production of electricity from renewable resources.

The landfill cover system at the ***Hickory Ridge Landfill*** *in Conley, GA, relies on a 60-mil reinforced, synthetic membrane covering 45 acres. The exposed geomembrane overlays 12 inches of an intermediate cover and a compacted grading layer. Approximately 7,000 flexible* ***PV panels are bonded to the membrane****, which is positioned on about 10 acres with 18° southern and western slopes. Power cables in flexible conduit extend to the edge of the cap where they connect to an inverter. The 1-MW facility is expected to annually generate 1.3 million kWh of electricity that will be sold to the local utility under a renewable energy purchase agreement.*

Depending on the cover type, project managers can explore ***other compatible uses of land*** with properly covered landfills, such as:

- Greenspace for wildlife preservation or recreation[20]
- Agriculture such as hay production, and
- Seed harvesting to revegetate other sites.

Project managers also can explore approaches for recycling portions of the onsite waste, as an alternative to capping that provides economic and land use benefits. Cleanup at the Fairmont Coke Works-Sharon Steel Site in Fairmont, WV, for example, involves excavating, sorting, and blending the various consitutents to form feedstock sold to a local synfuel power plant.

Waste not contained in landfills or in disposal pits but left in place may provide other reuse opportunities while significantly reducing land and ecosystem disturbance during cleanup. This approach requires assessment of potential human health risk posed by the remaining hazardous substances or constituents and likely involves long-term institutional controls, restricted use, and ongoing liability to site owners.[21] Low human health risk at a high-elevation mining site, for example, may not affect anticipated use of a site for purposes such as community recreation or power production from renewable resources.

In 2007, a ***2-MW solar farm*** *was installed atop a 12-acre monolithic* ***ET cover*** *for construction debris at* ***Fort Carson****, CO. The design included selecting a native seed mix that would yield shade and drought-tolerant vegetation with a short height.* ***Monitoring and O&M*** *indicates more successful vegetative growth in areas shaded by the ground-mounted PV panels than in non-shaded areas, with no evidence of erosion caused by the panels. Vehicle traffic inside the fenced solar farm is kept to a minimum to avoid land disturbance, particularly under wet conditions. No irrigation has been needed despite the site's semi-arid climate, and no chemical pesticides/herbicides have been applied.*

One round of early summer mowing to a four-inch height is typically sufficient to control weeds, minimize wildfire fodder, allow year-round light access across the site, and prevent shading of the PV panels. Periodic hand-washing of the solar modules is performed by using low-pressure hosing and heavily diluted vinegar. This ***maintenance is performed by the solar developer*** *(Conergy) under a 20-year contract with Carson Solar I, LLC, the project owner. In return, the owner sells the generated electricity to Fort Carson at a reduced rate under a 20-year power purchasing agreement.*

Monitoring and Maintaining a Final Cover

Proper O&M of a cover system and landfill closure elements such as a gas collection system is needed to ensure they are performing as intended. Monitoring and maintenance BMPs can involve simple but efficient procedural changes as well as advanced field equipment to increase efficiencies, such as:

- Minimize frequency of grass mowing, to reduce fuel consumption and disruption to ground-nesting birds
- Explore using controlled grazing by goats or sheep to eliminate woody growth and control vegetation height while adding organic matter to the soil
- Integrate onsite structures to capture rainfall as a source of water for work such as rinsing field equipment
- Use remotely controlled or non-invasive techniques, to avoid cover damage and minimize field visits; for example, open path spectroscopy techniques can be used to periodically check for escaping LFG[22]
- Explore onsite renewable energy to power auxiliary equipment such as weather stations, and
- Evaluate natural settings as indicators of long-term changes in the cover.

EPA encourages PRPs and owners or operators of sites requiring landfill cover installation to work closely with states and other agencies or organizations responsible for oversight of the system over time (commonly 30 years or more) and any site reuse. Partners may include non-profit groups serving the local or regional community.

Landfill Cover Systems & Energy Production: Recommended Checklist

Designing and Installing a Cover System

- ✓ Design with the intent of maintaining natural settings and addressing potential effects of climate change
- ✓ Maximize use of onsite rather than offsite materials
- ✓ Maximize use of materials with recycled or biobased content
- ✓ Reduce consumption of petroleum-based power through clean fuel/emission technologies and renewable energy resources

Landfill Gas Recovery for Beneficial Use

- ✓ Explore opportunities for direct use of treated LFG
- ✓ Install LFG recovery technologies to generate electricity and use any associated waste heat
- ✓ Partner with other organizations to produce fuel

Integrating Landfill Cover Designs with Reuse

- ✓ Consider a contact cover to serve as a biobarrier
- ✓ Explore electricity production from solar and wind resources, for onsite use or credit/sale
- ✓ Identify other activities that could maximize use of a covered area without jeopardizing the cover system

Maintaining and Monitoring a Final Cover

- ✓ Schedule periodic inspection of cover system components and quickly complete needed repair
- ✓ Use non-disruptive techniques and the site setting to monitor cover system performance
- ✓ Explore partnerships to integrate cover maintenance with site reuse

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

The Agency is publishing this fact sheet as a means of disseminating information regarding the BMPs of green remediation; mention of specific products or vendors does not constitute EPA endorsement.

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