Appendix E

Landfill Reuse

EXPANDING THE OPTIONS

Engineers seeking to help clients maximize the profitable operation of landfills well into the future should consider adding renewable energy technologies to the sites—and if the waste disposal areas can be increased by mechanically stabilized earth berms first, the opportunities for energy generation will multiply.

By Ranjiv Gupta, Ph.D., A.M.ASCE, and Jeremy W.F. Morris, Ph.D., P.E.

OVER THE PAST SEVERAL YEARS, Geosyntec Consultants, based in Boca Raton, Florida, has worked with numerous clients who as owners or operators of landfills have sought to increase the operational life of their properties and maximize their ability to profitably operate them even after they are filled, covered, and closed. In recent years, there has been a confluence of this desire with a goal to reuse the sites for purposes that benefit the community in tangible ways.

A popular approach to extending the operational life of a landfill is to increase its disposal capacity through vertical expansion made possible by a mechanically stabilized earth (MSE) berm constructed along the perimeter of the landfill's footprint. This certainly helps to keep normal landfill operations going for some time, but once the additional space has been filled, many landfill owners have become interested in adopting sustainable approaches that would enable them to continue managing the property after landfill closure. As an extension of a feasibility study recently undertaken for such a client, we examined how the twin goals of beneficial reuse and environmental stewardship could be combined by strategically integrating a vertical expansion with the construction of renewable energy technologies (RETs) at a theoretical landfill. We took the theoretical property from its operational state to its postclosure state, transforming it in the process from a waste disposal facility to a renewable energy

Two 80 m tall, 1.6 MW_p wind turbines are operating on a portion of the Frey Farm Landfill, in Creswell, Pennsylvania, that does not accept waste but is part of the overall site.

LANCASTER COUNTY SOLID WASTE MANAGEMENT AUTHORITY

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park. The results illustrate how a phased installation of these RETs could be implemented during and after the construction of an MSE berm at a landfill to optimize the beneficial reuse of the site. As engineers seek to assist their clients by developing ways to use and reuse landfill properties, the guidelines discussed here may be useful, and some of the approaches have already been implemented on a small scale.

Four RETs were evaluated as part of this study: solar photovoltaic (PV) arrays, wind turbines, methane gas utilization, and the use of the landfill as a geothermal heat source. The energy potential at the landfill from the four RETs is available in two major forms: electric energy can be generated using solar and wind sources, and heat or thermal energy can be obtained from methane and geothermal sources. These forms of energy become available in differing degrees at different stages of the landfill's life cycle. Therefore, a key focus of the study was determining the best time to construct and implement each RET and to optimize that timing in relation to the MSE berm construction. Although it is certainly not necessary to construct an MSE berm at a landfill to take advantage of the landfill's potential as a source of renewable energy, our study demonstrates that doing so significantly improves the site's energy generation potential for all four RETs over both the short and the long term. What is more, transforming a landfill into a renewable energy park would enhance the sustainable use of the property while providing renewable energy for the local community, offsetting the community's consumption of energy from fossil fuels and thus reducing its carbon footprint.

Modern landfills are essentially inground treatment vessels that promote natural organic waste decomposition and the conversion of raw waste from solid form to liquid and gas form. The by-products of the degradation process include landfill gas, which is typically 40 to 60 percent methane, and leachate, which is liquid that has passed through or emerged from the solid waste and contains soluble or suspended materials removed from the waste. To achieve their performance objective of protecting the environment while operating their landfills, owners typically use multiple systems simultaneously during all phases of the landfill's life, including operation, closure, and postclosure. The objective is to protect such sensitive receiving media as groundwater, surface water, unsaturated soil, and air, and these media are often monitored to ensure that the goals are met.

A typical landfill comprises a liner system, which contains the waste and its by-products and is typically a composite of clay and geosynthetic material; a leachate management system, which collects leachate to minimize the buildup of hydrostatic head above the liner and removes it for treatment and disposal; a landfill gas

The Hickory Ridge Landfill, in Conley, Georgia, is covered with a geomembrane that is inset with a 1 MW_p photovoltaic array.

AMERICAN ENVIRONMENTAL GROUP

management system, which collects the gas and removes it for thermal destruction (flaring) or renewable energy production; and, after closure, a final cover system, which provides long-term containment and controls the rate at which water enters the landfill from rainfall or snowmelt, provides storm-water management, protects the quality of surface water, and can also provide a suitable platform for beneficial reuse options.

Closed landfills offer significant potential for beneficial reuse, particularly as urban areas continue to expand at their boundaries. These reuse options can be passive, as seen in wildlife habitats, or active, for example, golf courses, recreation areas, parks, or grazing land; they can also be used to grow livestock feed or stock for making biofuels.

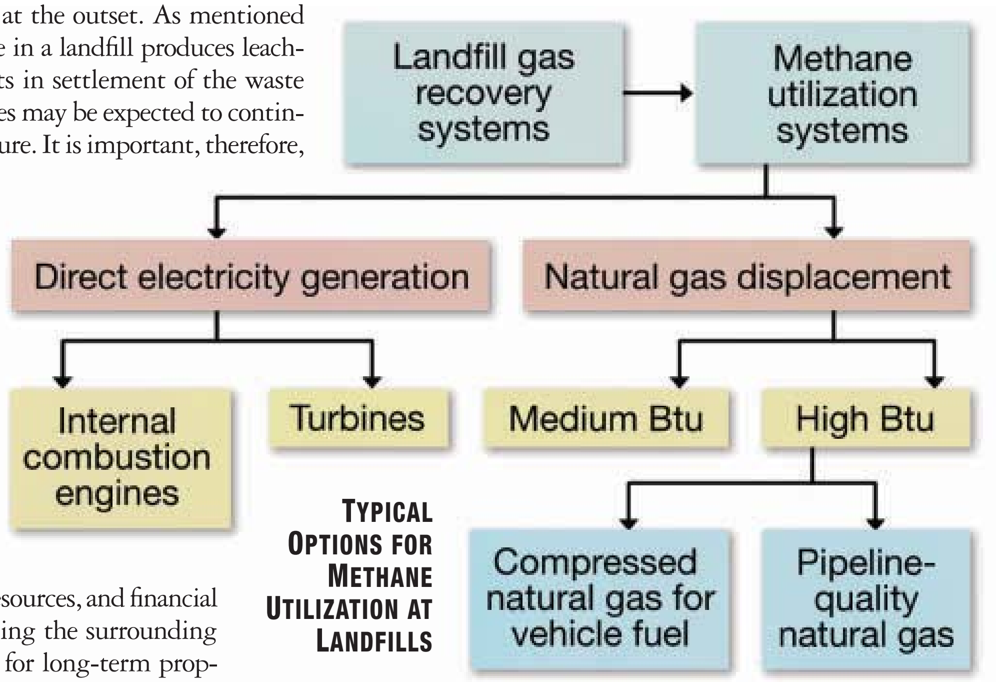
However, several geotechnical, hydrogeologic, ecological, and other factors that depend on the site in question may limit the number and type of reuse options available and should be clearly understood at the outset. As mentioned above, decomposition of waste in a landfill produces leachate and landfill gas and results in settlement of the waste body over time. These processes may be expected to continue for several decades after closure. It is important, therefore, that any proposed reuse of a site be compatible with maintaining the necessary long-term integrity and performance of the landfill's component systems, particularly the cover.

The main objectives of an environmentally responsible and sustainable landfill management strategy are to minimize, over the entire life of the project, the depletion of energy, material resources, and financial resources without compromising the surrounding environment or passing costs for long-term property management and monitoring on to future generations. In practical terms, any discussion of landfill sustainability and reuse must therefore include goals for the postclosure reuse of the landfill property. If these sustainability objectives are to be realized, landfill owners and operators will have to focus on reducing the potential environmental and financial liabilities of landfills by optimizing design, operation, and management over the lifetimes of the facilities.

Clearly, a key component of such optimization is the investigation of methods by which an active disposal facility can be made suitable for a compatible postclosure reuse. Planning enables the operator to implement strategies during late-stage operations that cannot be implemented after the landfill is closed. In our study, we examined the successful construction and operation of solar and wind RET projects at a closed landfill—the Stadtreinigung Hamburg, in Germany—for which revenues from energy production have exceeded the postclosure costs, even after accounting for the engineering work needed to meet the foundation requirements.

Most landfill-based solar power systems use PV cells, which convert sunlight into direct current using the photoelectric effect. PV systems can be designed to provide direct current or, if fitted with an inverter, alternating current, and the systems can operate independently or be connected to the utility grid. They can also be connected with other energy sources and energy storage devices. In northern climates, landfills offering significant south-facing exposure are ideal for the installation of PV systems. These systems typically take the form of stand-alone flat panels on support stands anchored above the landfill cover or of flexible thin-film panels glued to an exposed geomembrane cover.

It is estimated that more than 20 landfill-based solar projects were operational in the United States as of December 2011. A benchmark unit cost that is commonly used by the solar energy industry is the installed price per peak watt (W_p), which is defined as the capacity of a standard PV panel when exposed to standard conditions. This measure does not take into account actual solar conditions at a site; therefore, the solar radiation at the site must be considered separately when estimating the actual capacity of a PV system. (The actual average capacity for current PV technologies is in the range of 5 to 15 percent of peak.)



Typical Options for Methane Utilization at Landfills

The current capital cost of installing a PV system on a landfill is estimated at about $5 per peak watt, roughly 70 percent of which is for materials, 10 percent is for inverters and cabling, and 20 percent is for installation. On the basis of preliminary estimates, a 1 MW_p facility in the Middle Atlantic states would cost approximately $6 million and require 2 to 3 ha of land.

Wind power is created by converting the kinetic energy of moving air into mechanical energy using a wind turbine. Wind turbines can be divided into two major categories, depending on whether the axis is horizontal or vertical. The horizontal-axis wind turbine is significantly more common than its vertical counterpart and has the main shaft and generator at the top of a tower pointing into the direction of the wind. The vertical-axis wind turbine has the main

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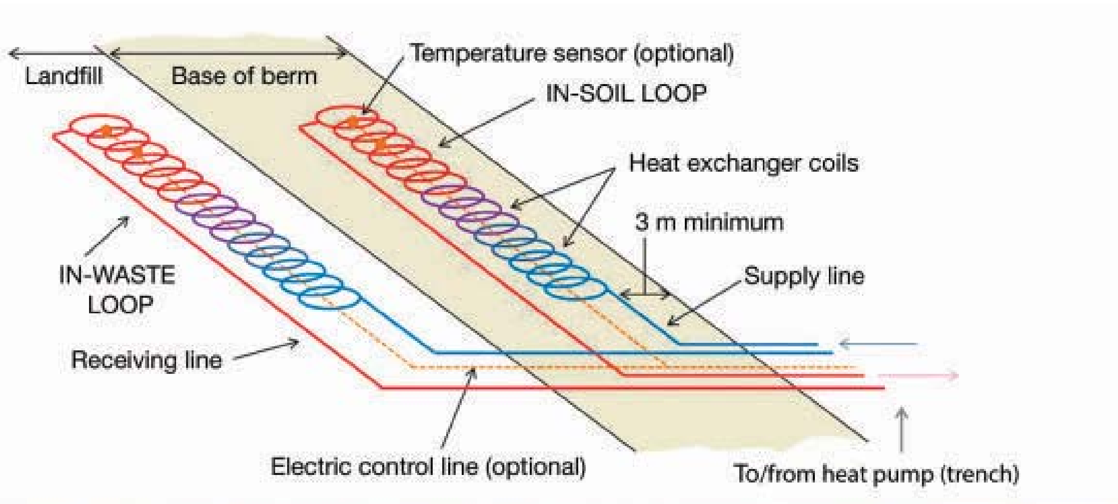
LANDFILL HEAT EXCHANGER PIPING IN WASTE AND BENEATH MSE BERM



A geothermal heat exchanger installed at the North Country Environmental Landfill, in Bethlehem, New Hampshire, generates 250,000 Btu per hour.

GEOSYNTEC CONSULTANTS, *TOP;* CMA ENGINEERS, INC., *BOTTOM*

rotor shaft in the vertical direction and can be placed independent of the direction of wind. These turbines can also be placed closer to the ground and thus are relatively easier to maintain. However, they are less efficient and have to be spaced farther apart than do horizontal-axis turbines. In both systems, the turbines power a rotor that produces direct current, which is typically inverted to alternating current for the power grid.

Wind turbines designed for onshore applications need moderate but steady winds and start producing energy as wind speeds reach 15 to 20 km/h. The efficiency of a horizontal-axis wind turbine depends on the amount of energy extracted by the blades (the swept area of the rotor), the installation height of the rotor, and the spacing between the towers (5 to 15 times the rotor diameter is recommended). Greater height provides better access to steadier winds of higher speed, and this is the main advantage of installing a turbine on top of a landfill.

The wind power industry rates a wind system in terms of its "nameplate" (peak) generating capacity, which assumes that the wind conditions prevailing at a site are available 100 percent of the time at the speeds required for maximum efficiency. The actual average capacity of a horizontal-axis wind turbine is typically about 25 percent of peak. The current capital cost for installing this type of turbine is about $3 per peak watt.

As of December 2011, two successful wind turbine systems were operating on landfill properties in the United States. Through a cooperative partnership, the Lancaster County Solid Waste Management Authority installed two 80 m tall, 1.6 MW_p wind turbines on a nonoperational portion of its Frey Farm Landfill, in Creswell, Pennsylvania. Electricity output from the turbines is supplied to an adjacent dairy products manufacturer. Enthusiastic support for "Hull Wind 1," a 660 kW_p, publicly owned turbine installed in Hull, Massachusetts, in 2001, led to the installation in 2006 at

PLANNING ENABLES THE OPERATOR TO IMPLEMENT STRATEGIES DURING LATE-STAGE OPERATIONS THAT CANNOT BE IMPLEMENTED AFTER THE LANDFILL IS CLOSED.

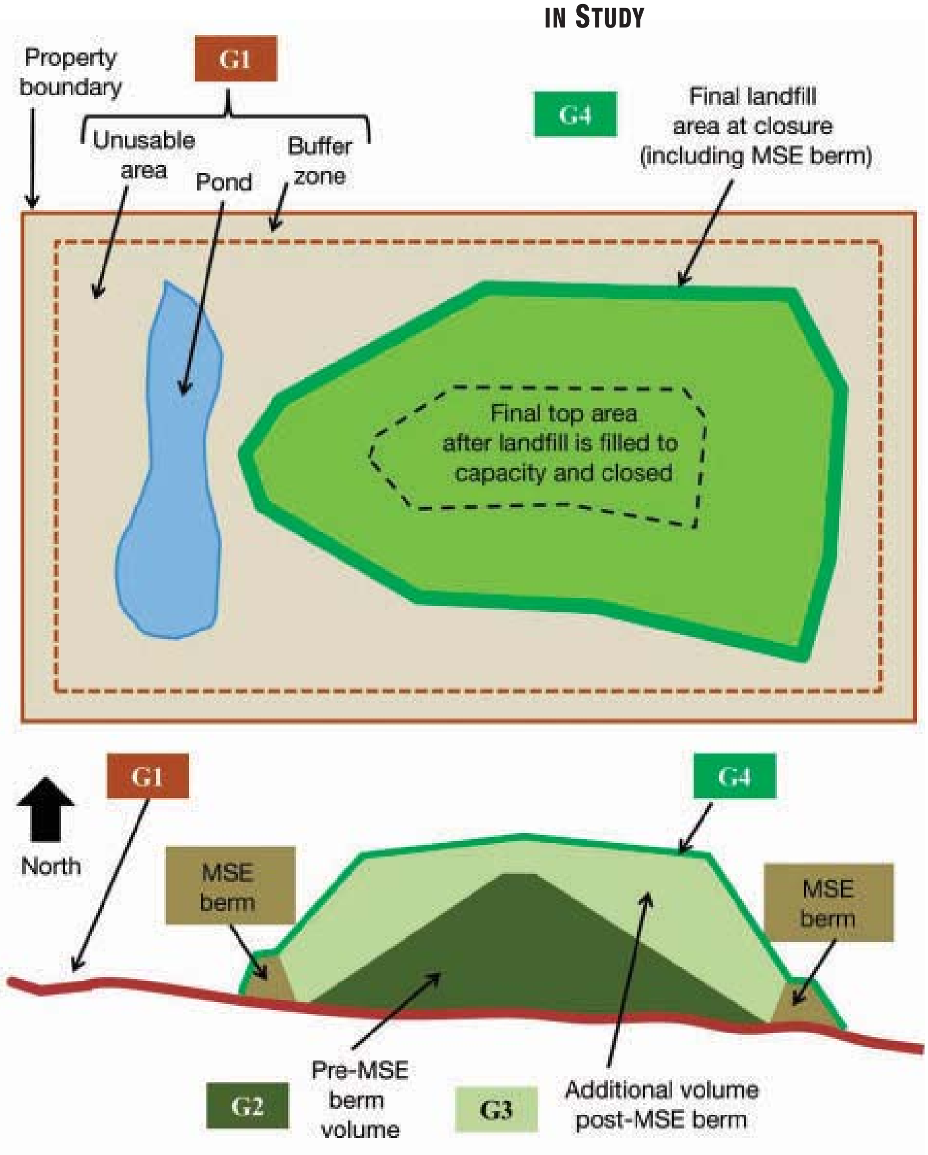
the closed Hull Landfill of "Hull Wind 2," which is larger, being 60 m tall, and has a capacity of 1.8 MW_P. The two turbines are operated by a volunteer organization of residents and supply more than 10 percent of the town's electricity.

Selecting a wind turbine system for a landfill must take into consideration the need for an appropriate foundation system to support the turbine. This is particularly true of tall horizontal-axis wind turbines, which experience high bending moments. Considering the significant compressibility of waste, the settlement and foundation stiffness requirements are critical to the design of a wind turbine system on such a site. The technical solutions that have been adopted include such preconstruction ground improvement techniques as dynamic compaction, the replacement of a layer of waste with less compressible material, and grouting. When greater deformation control has been required, deep foundations have been used.

While the wind turbine is being constructed, the transportation of its parts to the site may impose significant loads on the roadways that access the landfill, and these may therefore need to be upgraded. What is more, when the wind turbine is being erected, the work area that supports the construction equipment must have a sufficient bearing capacity. To satisfy these requirements, modifications to the existing final cover system may be necessary, for example, replacing certain areas of the final cover soil with stronger gravel fill or installing geosynthetic reinforcement.

Landfill gas is a natural by-product of the decomposition of organic waste material under anaerobic conditions. The biochemical degradation of organic material yields gas containing roughly 50 percent methane and 50 percent carbon dioxide by volume with trace concentrations (less than 1 percent) of volatile organic compounds and inorganic compounds. Methane in landfill gas has the same chemical characteristics as natural methane gas. Such medium-Btu gases as raw landfill gas have a heating value approximately half that of natural gas and can be used directly for electricity generation or to provide heat energy. It can also be used on-site in place of natural gas or can be sent to a nearby industrial facility. Moreover, it can be purified and the resultant high-Btu methane can be injected into the natural gas grid, and it can be used to produce compressed natural gas, an alternative vehicle fuel. (See the figure on page 76.)

PLAN VIEW AND CROSS SECTION OF HYPOTHETICAL LANDFILL USED IN STUDY



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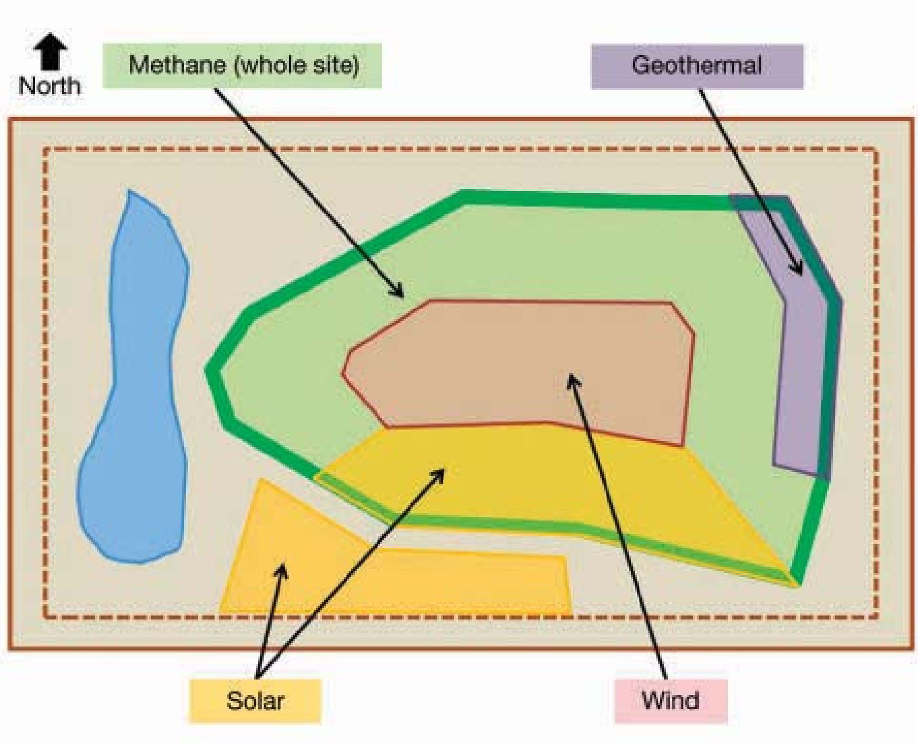
The collection of landfill gas is common and, in many circumstances, mandatory in the United States. Generally, the gas is collected by installing horizontal collector trenches as the waste is placed or by drilling vertical wells into the landfill after the waste has been placed. Trenches and wells are connected to controlling wellheads that transport the collected gas via lateral piping to a main collection header. Mechanical blowers are used to induce a vacuum in the collection system. The overall efficiency of gas collection at a landfill varies widely, from less than 60 percent to more than 95 percent, and depends mainly on the cover type, the timing of the installation, and operational factors. For those locations at which methane utilization is not practiced, the gas is simply flared as a control measure.

The goal of a methane utilization project is to convert the methane in landfill gas into useful energy by direct use or through electricity generation. Both of these options have three basic components: a gas collection system and a backup flare; a gas compression and treatment system; and an energy recovery system. The capital costs for such



Completed Transition of Hypothetical Landfill to Renewable Energy Park

a project generally include the costs for design engineering, permitting, site preparation, utility installations, equipment, startup, and training. The U.S Environmental Protection Agency estimates in its *LFG Energy Project Development Handbook* ("LFG" denoting landfill gas) that developing a well field at a landfill would entail a capital cost of roughly \$50,000 to \$60,000 per hectare. Key factors influencing this cost include the number and depth or length of the wells and trenches installed, as well as the total length and gauge of the lateral and header gas piping required.

Geothermal energy projects are developed to take advantage of the thermal energy from the earth. In the case of landfills, such projects capture heat generated by the decomposition of waste. A geothermal heat pump is a good fit for landfill applications, as it can pump heat from the waste or from the ground beneath an MSE berm. Geothermal systems take advantage of the stable, high temperature at the base of the landfill. The figure at the top of page 77 illustrates a conceptual cross section of a geothermal piping system that recovers heat both from the waste and from the ground beneath an MSE berm at a landfill. The heat exchanger unit requires an electrically driven compressor and heat exchanger to concentrate the heat for subsequent release inside the building or other structure that is being heated. The heat exchanger collects heat by means of supply and receiving loops that carry the heat exchange fluid (a saline solution) and are generally made of high-density polyethylene (HDPE) pipe, which is both durable and flexible.

The length of the pipes or ground loops depends on the heat and air-conditioning load, the depth of burial, the waste or ground conditions, the local climate, and the available land area. The first landfill-based geothermal project in the United States was recently installed in New Hampshire. This low-cost (\$50,000), small-scale (250,000 Btu/h) project uses heat exchanger loops installed directly on top of a 0.2 ha area of the landfill liner system and heats the maintenance building at the landfill.

The installed cost of a geothermal system depends primarily on the depth of the geoexchanger wells, the lengths of the pipes, the temperature of the geothermal fluid, the level of contaminants, and the ease of access to electrical transmission lines.

The cost involved in drilling the wells generally accounts for half of the total initial capital costs. However, if the geothermal system is installed as the landfill or its liner is being built or as the MSE wall is being constructed, no drilling is required; the pipes can be laid horizontally on the ground prior to berm construction, on the liner as it is being laid, or in the waste mass during active waste placement in the landfill. Based on the experience gained from the first U.S. project of this kind, it is reasonable to expect that about 1.25 million Btu per hour could be obtained for each hectare of installed heat exchanger loops. The cost of developing 1 ha in this way is estimated to be between \$200,000 and \$350,000, depending on the size of the heat pump and other facets of required infrastructure.

THE COST INVOLVED IN DRILLING THE WELLS GENERALLY ACCOUNTS FOR HALF OF THE TOTAL INITIAL CAPITAL COSTS. HOWEVER, IF THE GEOTHERMAL SYSTEM IS INSTALLED AS THE LANDFILL OR ITS LINER IS BEING BUILT OR AS THE MSE WALL IS BEING CONSTRUCTED, NO DRILLING IS REQUIRED.

Areas within a landfill can be broadly categorized as off-limits, inactive, or active. Areas that are off-limits are generally those that cannot be developed for landfill disposal but may be suitable for other uses. Such an area can be further subdivided into three types: areas that can be used to create a buffer zone to meet setback requirements but are otherwise unsuitable for development for topographical, ecological, operational, or other reasons; areas that contain ponds for storm-water management and other surface water features or wetlands; and areas that are required for the operation and administration of the facility, including access roads, scales, scale houses, offices, buildings, maintenance shops, citizen recycling and drop-off centers, and landscaped areas.

Inactive areas are those portions of the landfill that have achieved their final elevations and can no longer be used for waste disposal. An active area is still being used for landfill waste placement. If an MSE berm is constructed for a vertical expansion of the landfill, the area enclosed by the berm is considered part of the active area until the landfill is filled to capacity.

In our study, a hypothetical landfill property was divided into four groups broadly consistent with the categories outlined above. The category G1 includes areas of the landfill property that are off-limits and are outside of the current and proposed limits of waste disposal. G2 is the total waste volume that is in place prior to the construction of an MSE berm; its surface comprises both inactive and active areas. G3 indicates the volume of additional waste that can be placed atop G2 after the MSE berm has been constructed and therefore represents an area that will be active in the future. And group G4 encompasses the external, inactive surface of the landfill and MSE berm once the expanded landfill is filled to capacity and closed. G4 essentially encompasses G3 and the berms. The figure on page 78 presents a plan view and cross section of these areas. It is assumed here that during the vertical expansion of the landfill the footprint of the current landfill area will remain largely unchanged and that the MSE berm will be constructed along the landfill's perimeter.

We first turned our attention to installing a PV system, the size of which would depend on the extent of the south-facing slopes available. Land within G1 depends only on geometry and operations and offers immediate potential for PV development. The deployment of solar panels on the current surface of G2 is limited because so far no areas of the landfill have achieved their final elevations. As a result, slopes cannot be graded to achieve the maximum efficiency for installed solar panels. G3 never offers an opportunity for solar, as it will be covered by G4, and installing a PV system atop G3, even temporarily until G4 is created, would not be cost effective. The best opportunity to install solar panels will exist on the south-facing side slopes within G4 after closure.

Onshore wind turbines are generally feasible when installed such that their rotor height is at least 75 m above the surface of the surrounding terrain. Thus, the top surface of G4 represents an optimal location. G1 areas are unlikely to offer sufficient elevation. The surface of G2 may offer limited opportunities if future development of the landfill does not significantly change the final grades in the selected locations. Again, installing such a system on G3 would offer no realistic opportunities, as it would be subsumed by G4.

Because methane collection infrastructure is for the most part subterranean, it can be installed during the active landfilling phases of both G2 and G3. Horizontal collectors are preferable because they allow ongoing waste placement without the need for vertical extensions (which would be needed if vertical wells were to be installed). Vertical wells can be sunk through the entire depth of waste in G4 once the landfill achieves its final grade, but it is recommended that as much gas collection infrastructure as possible be installed during the life of the facility once a decision has been made to recover methane. The G1 area offers no opportunity for methane.

It is important to note that geothermal energy systems are significantly different from other RETs in that excess heat energy cannot be stored in a grid or used to generate electricity. It is also unable to directly offset natural gas or other fuel usage. The extent to which a geothermal system is developed therefore generally depends on the demand from nearby users for direct heat. To avoid deep trenching and minimize costs, it would be advisable to install any geothermal heat exchanger loops during construction of the MSE berm and the lining of the internal berm slopes—in other words, within G3. G1 areas also can be developed for ground-based geothermal energy, but this does not take advantage of the heat capacity of the waste.

The table on page 81 gives the best times for deploying RETs for each of the four areas.

The figure on page 79 illustrates the completed energy park after the RETs have been installed in G4 at the hypothetical landfill. (Areas within G1 are assumed to be available throughout the life of the landfill and are independent of the landfill activities.) It is assumed that a small unused area of G1 in the southern part of the property could be immediately developed with PV systems.

G2 represents the landfill waste mass before construction of the MSE berm and offers only methane collection as a viable RET. G3 does provide an opportunity for the installation of a geothermal system, as well as a methane collection system. It is therefore assumed that the methane collection infrastructure will be in place throughout the life of the landfill and will be present during the G2 and G3 stages. A small geothermal loop also will be installed as early as possible within G3. This will be when the first part of the MSE berm is being constructed. In this study, it was assumed that the paucity of users of heat energy in the vicinity of the site would preclude further development of geothermal loops. However, it should be noted that significant additional heat exchange capacity exists. Given the relatively low cost and the ease of loop installation in conjunction with liner construction, it may be worthwhile to install more loops than there is currently demand for and to advertise the availability

ONSHORE WIND TURBINES ARE GENERALLY FEASIBLE WHEN INSTALLED SUCH THAT THEIR ROTOR HEIGHT IS AT LEAST 75 M ABOVE THE SURFACE OF THE SURROUNDING TERRAIN.

of renewable heat energy to current or future landfill neighbors (a "build it and they will come" approach).

Finally, once the landfill is filled to capacity and closed, G4 comes into existence. This surface area is most suitable for solar and wind installations. In addition, after waste filling commences and the landfill is filled to its final grade, vertical wells can be installed through the G4 area to supplement methane collection from horizontal collectors installed in G2 and G3.

Opportunity Time Frames for Deploying Renewable Energy Technology

GROUP	RENEWABLE ENERGY TECHNOLOGY				WINDOW OF OPPORTUNITY FOR DEPLOYING TECHNOLOGY
	SOLAR	WIND	METHANE	GEOTHERMAL	
G1	Yes	Yes	No	Yes	Time not a factor
G2	No	No	Yes	No	Through completion of MSE berm construction
G3	No	No	Yes	Yes	From completion of MSE berm construction to closure
G4	Yes	Yes	Yes	No	After closure

What became clear from this study is that increasing the capacity of a landfill through the construction of an MSE berm can aid the development of all four RET types. The construction of an MSE berm could be designed to significantly increase the area covered by the southward-facing side slopes, which would provide a larger area for the deployment of solar arrays with higher incident solar radiation exposure. Increasing the top deck area available at the highest elevation of the landfill after the MSE berm has been constructed would facilitate the installation of wind turbines with rotor heights significantly above the surrounding terrain. As mentioned above, higher elevations provide access to steadier winds of higher speed. With a vertically extended landfill, there will be no need to construct excessively tall turbine towers. A larger top deck area would also make it possible to install a larger number of turbines, increasing the total generating capacity and enabling the power interconnection infrastructure to be used for more turbines.

It should also be noted that the rates of methane production are highest in new waste and decrease exponentially with time. Thus, increasing the total quantity of waste and the period of waste placement in the landfill would therefore not only increase the total methane yield but also overcome any limits on the scale and duration for which methane utilization is practical from a technical and economic perspective. Finally, constructing an MSE berm would make the implementation of a geothermal system more cost effective. After the berm was constructed, the amount of waste in place in the landfill would increase, thereby increasing the total heat capacity of the landfill. This would also help overcome limits on the scale and duration for which operating a geothermal system is practical from a technical and economic perspective.


Gupta


Morris

Most RET deployments, in particular, those using solar and wind sources, are capital intensive and require a long payback period. This is often the key factor limiting the development of such projects. By providing more certainty that the landfill will remain in profitable operation for a period beyond what is required for RET projects to become financially viable—generally at least 15 years—engineers can help owners make long-term decisions about capital investments for RETs. Furthermore, an active landfill operation will provide a diversified income stream and reduce the financial risk associated with developing an energy park.

RETs in the form of solar panels and wind turbines have been implemented on a number of landfills while they were in operation and after they were closed. Hundreds of landfills across the United States have installed systems for recovering methane for generating electricity and other purposes. However, only recently has a landfill in the United States harnessed the heat capacity of waste by means of a geothermal system. This study reveals that pursuing a "mixed-use" energy park strategy would enable a single landfill to offer four major RETs and remain economically viable for many years into the future. In this scenario, expanding the landfill would increase the renewable energy potential in the local area, which could help nearby communities reduce their carbon footprints by relying to a lesser extent on fossil fuels. What is more, utilizing the existing landfill footprint for a longer period through the construction of an MSE berm would certainly be a more efficient way to manage waste and would minimize the need to develop new waste disposal facilities.

Implementing RETs at landfills would also benefit the site owners by providing additional financial resources to fund maintenance activities, thereby preventing the marginalization of landfill properties after closure. Transforming a waste disposal facility into a renewable energy park thus provides a way to beneficially reuse the property—a clear demonstration of sound environmental stewardship. **CE**

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