CHAPTER 6 - Harnessing Landfill Gas as an Energy Source

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Introduction

There has been significant recent interest in reclaiming real estate formerly occupied by municipal landfills. Recent changes to regulatory programs offer both opportunity and new challenges for converting old landfills into productive real estate development.

Throughout North America, agencies of federal, state and local government have begun new initiatives to redevelop formerly used sites which are "tainted" environmentally. The initiatives have been given various names, including land recycling in Pennsylvania, and brownfield at the U.S. Environmental Protection Agency (EPA).

From the legal perspective, there are several concerns that must be addressed when redeveloping a former landfill site for a productive use. Liability concerns regarding potential environmental claims under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund) can dissuade private developers and their lenders. Technical challenges to reusing landfills include the problems presented by settlement, foundation support, gas generation, and worker health and safety.

Alternative Uses

The range of possible beneficial end uses for closed municipal solid waste landfills extend from "relatively passive" uses, through a group of "relatively active" uses, and ultimately to high value "intense" end uses. Examples of successfully applied municipal solid waste landfill end uses include:

- **Relatively passive**: Green space, wildlife habitat, and biking/walking/running trails.
- **Relatively active**: Golf courses, baseball/soccer fields, drive-in theaters, amphitheaters, and airfields.
- **Intense**: Office buildings, hotels, and shopping centers.

In selecting an end use for a landfill, the notion of the selection and application of the "highest and best" use is increasingly governing decisionmaking by landfill owners. The highest and best use for a closed landfill must be determined on a case-by-case basis. Individuals who are driven solely by economics will assume that the highest and best use for a particular landfill is always the most intense possible use at that landfill. A landfill owner might decide, however, that a regional park is the highest and best use for a landfill even if the site has great commercial potential.

It is not the purpose of this chapter to describe the process through which highest and best use for a closed municipal solid waste landfill should be determined–that process could be the subject of another chapter. This chapter will limit itself to a discussion of the implementation of relatively active and intense end uses at closed landfills. The purpose of mentioning the highest and best use concept is to emphasize that the most intense use possible for a site may not be the preferred use in many instances.

Legal Issues

Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund), owners or lessees of facilities from which there has been a release or a threatened release of a hazardous substance can be liable for all public and private costs of response to the release, even if the release took place many years earlier. The liability can be imposed even if the facility owner or operator was not negligent (the liability is "strict"). And response costs for typical landfill sites under Superfund can be substantial (e.g., the U.S. Environmental Protection Agency assumes an average $25-30 million for sites listed on the Superfund National Priorities List).

The prospect of strict, joint, several, retroactive, and substantial liability for Superfund response costs presents a challenge for anyone seeking to redevelop a landfill. Of course, such environmental stigma are not unique to landfills; many former industrial properties also lie dormant and undeveloped due to Superfund concerns. The new term of "brownfield" has been given to restoring tainted properties to productive use by overcoming the stigma associated with limited or moderate environmental contamination caused by previous site uses.

Federal and state agencies have begun to address the brownfield problem with a series of initiatives. The U.S. EPA announced a series of new policies and initiatives in 1995 to promote redevelopment of brownfield areas. These include increased use of negotiated covenants not to use Superfund to sue developers trying to redevelop tainted lands, and new policies not to pursue innocent landowners affected by migration beneath their property of contaminated groundwater from offsite.

Municipal owners of landfills also will benefit from several U.S. EPA Superfund initiatives which recognize the unique position municipalities hold as government agencies primarily responsible for the health and welfare of their citizens. Superfund is not well suited to municipal landfill sites, in which large quantities of household trash are mixed with relatively small amounts of hazardous substances from industry. U.S. EPA has announced a presumptive remedy for landfill sites (capping), and has demonstrated a new flexibility in dealing with municipalities which own landfills.

Technical Issues

As it ages, municipal solid waste in a landfill decomposes and consolidates. Active settlement can take place for many years, depending upon the depth of the trash fill, the types of wastes present (e.g., construction and demolition waste versus municipal solid waste), and the method of placement (e.g., trench versus area fill). Before buildings or other improvements can be constructed on a landfill site, estimates of expected settlement must be made based upon experience, empirical settlement observations, and numerical models.

Heavy loads will surcharge the waste mass and accelerate consolidation and settlement. Many site operators stockpile cover soils or excess waste on portions of the landfill prior to final closure. Such operating practices should be identified and considered when estimating settlement and differential settlement rates.

Although some buildings have been constructed using floating foundations (normally after replacing a few feet of the underlying trash with structural fill), most larger buildings and sensitive structures constructed over landfills utilize deep foundations (e.g., piles or caissons). A combination of the two approaches has been used over old shallow landfills, in which building walls are constructed on piles or caissons, while a floating slab is used for the building floor.

The result often is a stable building, surrounded by a settling ground surface as the underlying landfill consolidates. At one California landfill, a hinged slab was connected to a retail building on one side, and allowed to "float" with the land surface on the other side. If settlement causes the slab to sink too far on the floating side, it can be jacked up and the land surface regraded to create a proper entranceway to the building.

Where utilities enter natural ground or fixed structures supported on deep foundations, allowance must be made for differential settlement. Flexible utility connections have been developed for such applications. Pipe runs beneath buildings constructed on deep foundations should be hung from the overlying structural concrete slabs with non-corrosive hangers, and surrounded by non-cohesive backfill material. Otherwise, settlement of the underlying fill could cause the pipe to be pulled away from the building.

Settlement

If possible, the buildings should be located on native soil outside of the landfill footprint. Generally, this is not possible unless the site has a refuse footprint which is accompanied by a large undisturbed native soil area. When the building is located on refuse, it will be necessary to install piles to support the building. The problem with piles is that while the building is stable, the surface around the building settles, producing what some architects refer to as a "hard edge" settlement problem.

The principal problems associated with settlement are: (1) building ingress/egress is ultimately impaired; and (2) utility connections to the building begin to shear off. Architects have developed innovative solutions to these problems, including:

- Hinged slabs at entryways to buildings (which greatly decrease the intervals between the need to regrade around the building entries while still maintaining a seamless entry);
- Flexible utility connections for both pressure and gravity utilities (which can accommodate all of the expected vertical settlement); and
- Hangers embedded in the slab (which attach to utility pipes located under the slab). The hangers allow the pipe to hold its horizontal position with respect to the building as the landfill cover and refuse moves downward.

The areas surrounding commercial buildings are generally parking areas. Settlement of these areas is a concern for three main reasons:

- Drainage patterns can change (due to differential settlement);
- The grade of below-surface gravity utilities (wastewater and storm water) can change; and
- The slope of the surface may change to exceed the grade required by a specific project architectural design standard. As an example, the slope of a parking lot may not be permitted to exceed a certain grade because of the damage which could be done by runaway shopping carts. Such a standard would apply to a shopping center but not to an office building.

Architects sometimes call the above types of settlement problems "soft edge" settlement problems. These problems are best addressed through grading plans developed which fully consider landfill settlement projections. Settlement projections are generally summarized in the form of a site map which shows projected differential settlement in a contour format. Areas of high settlement can be somewhat overfilled with cover soil to partially compensate for long-term settlement.

Landfill Gas Control

As solid waste decomposes, landfill gas (LFG), consisting of methane and carbon dioxide, is produced. If allowed to accumulate within a confined area in the presence of an ignition source, methane can explode. Any improvements constructed on or near a landfill should incorporate appropriate LFG protection measures.

Several approaches are available to protect structures from LFG. Active control technologies include LFG extraction (normally followed by flaring, if gas production rates warrant treatment) to remove landfill gases before they reach structures, and air injection or air curtain systems to create positive pressures, driving landfill gases away from structures.

Passive control technologies include use of membrane barriers and vents to prevent gases from entering structures, and monitoring and alarm systems to warn of accumulating gases. Passive systems are commonly used where the landfill is old, and most of the decomposition has occurred (i.e., gas production rates are low). Passive systems also may be appropriate where the building will have limited usage, or is of open construction (e.g. open parking structures having six or more air changes per hour).

LFG control systems protecting higher occupancy buildings often have redundant systems (e.g., barriers, active extraction, and monitoring alarms), especially when the landfill is not old. Special care must be taken where utilities or other site features penetrate barrier systems. LFG will follow preferential flow paths along utility trenches and enter buildings at points of penetration unless properly sealed.

LFG protection systems require proper operation, monitoring, and maintenance. Monitoring alarm sensors can become "poisoned" by LFG constituents and rendered useless. LFG condensate and corrosive gas constituents can affect mechanical systems. As the closed landfill ages, LFG production patterns change, requiring adjustments in extraction system operation.

Landfill gas control is driven primarily by safety concerns. The goal is to prevent explosive levels of methane from accumulating in buildings and in confined spaces. Building protection can employ one or more of the following approaches:

- a membrane below the building slab plus explosive gas monitoring (inside the building or under the building between the membrane and the slab);
- a membrane and gas monitoring system plus passive horizontal vents under the building slab/membrane;

- a membrane and gas monitoring system plus active horizontal vents under the building slab/ membrane. Active horizontal vents take the form of a forced air blower feeding air injection pipes, which alternate with vent exhaust pipes, to flood and purge the subslab area with air;
- an active vertical extraction well system installed within the refuse mass;
- an active horizontal collector system located in the refuse mass;
- an active vertical extraction well system in soil;
- an air dike system located in soil;
- passive vertical or horizontal vents in the refuse; and/or
- a passive trench barrier in the refuse and/or in the soil.

The approach employed on a specific project depends on:

- whether the building is actually located over the refuse mass
- how close the building is to the edge of the refuse mass (if the building is not actually to be located over the refuse mass)
- how much refuse is present and the age of the refuse (these factors being reflective of how much landfill gas is actually being generated)
- land use around the building (parking, recreational facilities, open space, etc.)

While some county and city governments have regulations governing building protection, many jurisdictions do not have regulations. In these instances, it is necessary to rely on engineering judgment. Even when regulations exist, they are usually not thoroughly prescriptive. An example of a fairly typical nonprescriptive code is the Los Angeles County Uniform Building Code in §110.3, which states:

> ***Fills Containing Decomposable Material.*** *Permits shall not be issued for buildings or structures regulated by this code within 1,000 feet (304.8 m) of fills containing rubbish or other decomposable material unless the fill is isolated by approved natural or artificial protective systems or unless designed according to the recommendation contained in a report prepared by a licensed civil engineer. Such report shall contain a description of the investigation, study and recommendation to minimize the possible intrusion, and to prevent the accumulation of explosive concentrations of decomposition gases within or under enclosed portions of such building or structure. At the time of the final inspection, the civil engineer shall furnish a signed statement attesting that the building or structure has been constructed in accordance with the civil engineer's recommendations as to decomposition gases required herein.*
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> *Buildings or structures regulated by this code shall not be constructed on fills containing rubbish or other decomposable material unless provision is made to prevent damage to the structure, floors, underground piping and utilities due to uneven settlement of the fill. One-story light-frame accessory structures not exceeding 400 square feet (37.2 m2) in area or 12 feet (3658 mm) in height may be constructed without special provision for foundation stability.*

Landfill Gas Energy Recovery

More often than not, landfills associated with commercial developments are relatively old and small. The size of these landfills limits their potential for energy recovery. It is often possible, however, to satisfy part or all of the energy requirements of building tenants at small landfills in several ways:

- Fire landfill gas alone or co-fire landfill gas with natural gas in boilers to generate steam and/or hot water;
- Use the hot water or steam to produce chilled water; and/or
- Fire landfill gas alone or co-fire landfill gas with natural gas to generate electric power using "distributed generation" technologies.

Direct Use Technologies

The first two of the bulleted items above are so-called direct use or medium Btu technologies for LFG energy recovery. As extracted from a landfill, landfill gas has about half the fuel value of natural gas. Landfill gas is generally about 50% methane, or 500 Btu's per cu ft. This compares to natural gas with essentially 100% methane, and a fuel value of 1000 Btu's per cu ft. In direct use of landfill gas, the LFG is collected and used in a medium Btu or "as is" condition. Gas treatment may be applied to clean the collected gas of particulates and moisture. Other than that, the trace gas impurities and large carbon dioxide content (the latter at about 50%

on a volume basis of the collected gas) is left with the gas as it is passed along for consumption. Most boilers and other combustion technologies can utilize this medium Btu landfill gas with relatively minor adjustments to combustion temperature and feed air. Other than that, combustion of LFG occurs under the same principles as that for natural gas - it just takes twice the volume of landfill gas to achieve the same Btu heat output as natural gas.

Direct use technologies can be applied to off site or on site customers. Space and water heating is a common application for landfill gas collected in this manner. Unfortunately, space heating may be a seasonally variable load, or even a small load in warm climate areas. For this reason, a large industrial customer, with a large need for natural gas on a continuous basis, and located near the landfill is often a better customer for collected landfill gas. Generally, such industrial customers must be located within about 3 to 5 miles of the landfill for the economics of gas transmission to work out.

Of course, closed landfills are often on the downside of gas volume production, and thus transport to off site customers may not justify the high capital cost of off site transmission. In these cases, on site use may be more viable, even if the energy load is for heating and of a seasonal nature. The fact that the gas must be collected anyway in many cases to protect the construction on site may mean that the viability of direct use of landfill gas is based only on the added cost associated with retrofitting an existing control system to an energy recovery system. In this case, direct use of collected medium Btu gases is the most common application, usually for space and water heating.

Microturbine Operations

Reciprocating engines have been widely used at landfill gas fired electric power plants on larger and active landfills which still generate large quantities of gas, and which are expected to do so for many years into the future. At these sites, gas generation is rising and expected to stay at high levels for 20 years or more into the future. The higher capital costs associated with such plants can be readily justified over the longer amortization periods found on these kinds of sites. Moreover, reciprocating engines do not tolerate low methane content landfill gas and are not routinely equipped for landfill gas service in sizes below 800 kW. The applications under consideration herein would generally be less than 500 kW. Lastly, reciprocating engines emit relatively high levels of NOx, and may be difficult to permit in metro areas that are in non-attainment for certain air pollutants like NOx.

A potential solution to the difficulties associated with the use of reciprocating engines is to employ microturbines. Microturbines are currently available as smaller-scale 30 kW and 70 kW modular units. They can be marshaled in parallel to match the power requirements of a tenant and to work within the limitations imposed by the limited landfill gas availability, as is often found with development atop small and closed landfills on the down-side of their gas generation potential.

Microturbines can operate on methane contents as low as 30 to 35 percent versus the 40 to 45 percent typically required by reciprocating engines. Microturbine NOx emissions are as low as one-tenth the NOx emissions from reciprocating engines. Microturbines can easily be equipped to cogenerate electric power and hot water. As of February 2002, the U.S. had one landfill gas-fired microturbine power plant in operation, two under construction, and two under design.

The microturbine is a recently commercialized distributed generation (DG) technology. As of February 2002, three companies manufactured and sold microturbines -Capstone Turbine Company (Chatsworth, California, USA); Ingersoll-Rand (Portsmouth, New Hampshire, USA); and Bowman Power (Southampton, England). Honeywell Power Systems (Albuquerque, New Mexico, USA) did manufacture microturbines, but decided to exit the microturbine business in September 2001 after delivering more than 300 units. At least two other firms were offering microturbines for sale by mid-2002, including: Turbec (Malmo, Sweden), and Elliott Energy Systems (Jennette, Pennsylvania, USA).

The sizes of the microturbines offered or to be offered by the above manufacturers are as follows:

Capstone	30 kW and 60 kW
Ingersoll-Rand	70 kW
Turbec	100 kW
Elliott	80 kW
Bowman	80 kW

All of these microturbines can be equipped with either internal or external heat recovery units to generate hot water.

Most microturbine installations to date have employed natural gas as their fuel. Permanent (versus experimental) microturbine installations have also burned oil field flare gas, municipal wastewater treatment plant digester gas, and landfill gas. As of September 2001, there were about 100 microturbines operating on waste fuels. As a result of Honeywell's departure from the business, the number of microturbines operating on waste fuel temporarily decreased. As of February 2001, the longest run time for a microturbine on natural gas was about 20,000 hours. The longest microturbine run time on waste fuel was about 12,000 hours.

If natural gas or waste fuel is unavailable, other conventional fuels, including kerosene and propane, can be employed.

Operational Configurations for Microturbines

Like any DG project, a microturbine project can operate in one of four modes:

- Totally off-grid with no connection to a utility power supply;
- Disconnected from the utility grid when operating (main breaker open), but connected to the grid if the microturbine is off line;
- Always grid connected (parallel operation) with no export of power; and
- Always grid connected (parallel operation) with export of power intermittently (or always) to the grid.

The control system and protective devices for each of these alternatives vary slightly. In the first three cases, the microturbine facility must match its output with the host load at all times. In the third case, the facility is normally equipped with reverse power protection to prevent export. In the fourth case, the facility would be required to install all protective devices required by the utility for full, continuous parallel operation.

Description of Microturbine Technology

The microturbine is similar to the much larger combustion turbines employed in the electric power and aviation industries. Combustion air and fuel are mixed in a combustor section, and the release of heat causes the expansion of the gas. The hot gas is sent through a gas turbine which is connected to a generator. The microturbines are equipped with a recuperator which heats the combustion air using turbine exhaust gas in order to increase the unit's overall efficiency. The combustion air is compressed using a compressor which is driven by the gas turbine. The fuel must be supplied to the combustor at 70 psig to 80 psig. In some natural gas fired applications, the gas is available at this pressure from the pipeline. In waste gas applications, a gas compressor is always required.

A typical microturbine installation would have some or all of the following components:

- fuel gas compressor(s) or pump(s)
- gas pretreatment equipment
- Microturbine(s)
- motor control center
- switchgear
- transformer

Fuel gas compressors and/or fuel pumps are required if the fuel is not available at the desired pressure. A motor control center is required only if fuel supply compressors or pumps are required.

The extent of gas pretreatment depends on the characteristics of the waste fuel. Conventional fossil fuel requires no pretreatment. High hydrogen sulfide content oil field flare gas has been successfully fired without pretreatment. Other waste fuel applications, including landfill gas, have required some measure of pretreatment. The recommended fuel pretreatment steps required for waste fuel varies by manufacturer. In some instances, the waste fuel is chilled to remove moisture and condensable impurities, and the reheated to supply a fuel above dew point temperature, and then is sent to the microturbine. Some manufacturers require an adsorption step (activated carbon) to remove virtually all impurities, in addition to moisture removal.

A transformer is generally required to match generation voltage with line voltage.

Microturbine Applicability

Microturbines are most applicable where the following circumstances exist:

- Electric power is not available or is costly.
- Waste fuel is available or fossil fuel costs are relatively low as compared to power costs.
- Air emissions are of great concern.
- Emphasis is being placed on satisfaction of on-site power requirements, rather than exporting power.
- A requirement for hot water exists at the user.

Microturbines can operate on waste gases with a methane content of as low as 30 percent. A 70 kW unit requires less than 50 cfm of waste gas (at 35 percent methane content). Microturbines can be used where waste gas quality and quantity would not support reciprocating engines.

Air emissions from a microturbine are much lower than for a reciprocating engine. Microturbines have demonstrated NOx emissions less than one-tenth those of the best performing reciprocating engines. The NOx emissions from microturbines are generally lower than the NOx emissions from a waste gas flare. Diversion of waste gas from a flare to a microturbine can reduce a site's overall NOx emissions.

The highest power value for a microturbine project will be seen in the form of retail deferral. Retail deferral is the replacement of purchased electric power by self-generated power. In virtually all cases, the rate paid for retail power, discounted by the adverse impact of utility standby power charges, exceeds the rate that the utility or the wholesale market would pay for power exported off site.

Single or multiple microturbines offer the opportunity to configure small projects, and to configure projects that closely satisfy on-site power requirements. This capability is important for maximizing project economics by offsetting retail power costs without excessive export of power at wholesale rates. Prior to the availability of microturbines, many projects intended to supply onsite electrical needs were not deemed feasible because the available generation equipment size was much larger than the need. The resulting excess power sold to the utility at avoided costs would usually translate to an unacceptable rate of return for the project.

It is possible to produce hot water (up to 200(F) from the waste heat in the microturbine exhaust. Microturbine manufacturers offer a hot water generator as a standard option. Hot water users (such as hotels, hospitals, industrial or institutional buildings, etc.) can sometimes benefit from a small cogeneration project. A 70 kW unit can produce 0.3 to 0.4 MMBtu/hr of hot water.

Microturbines generally have applicability on projects normally spanning 30 kW to 800 kW in required capacity.

Microturbine Benefits and Liabilities

Of the three major combustion-based power generation technologies (reciprocating engines, combustion turbines and steam cycle), only reciprocating engines are available to compete with microturbines in the less than 1,000 kW range. Fuel cells are currently more costly than microturbines on an initial capital cost and life cycle cost basis.

Microturbines have the following advantages as compared to reciprocating engines:

- lower air emissions
- availability in completely pre-packaged units (with heat recovery, if desired) in smaller incremental capacities
- ability to burn a lower methane content waste gas

Disadvantages of microturbines as compared to reciprocating engines include the following:

- a higher heat rate (more fuel consumed per kWh produced)
- limited experience. Reciprocating engines are a widely proven, mature technology in the power generation business.

The higher heat rate of the microturbine is generally not an issue on waste fuel applications; however, it may be an important consideration on fossil fuel projects.

Health and Safety Issues

Landfills contain wastes, some of which may be hazardous. Older landfills-those which predate regulations requiring hazardous wastes to be managed in separate hazardous waste facilities-can contain a variety of industrial wastes such as solvents and sludges which require special handling and care if excavated. Many landfills were used to dispose of asbestos-containing building materials, which also require special handling and regulatory notifications.

Workers who may be exposed to hazardous substances during excavation of utility trenches or other subsurface site features should be properly trained to handle such materials safely. Work space air monitoring and perimeter air monitoring may be necessary to assure that site workers and neighbors are not harmed by migrating chemicals. Documentation of training, monitoring, and medical monitoring may be required by federal or state regulations. If drums of liquid wastes or other special materials are encountered during the construction activities, special contingency plans should be put into effect to characterize and stockpile such materials.

A written health and safety plan, specific to work on landfills, should be prepared and followed during construction. The Solid Waste Association of North America has published "A Compilation of Landfill Gas Field Practices and Procedures" (March 1992) which provides some common-sense elements for such plans.

Desirable Landfill Attributes

Desirable landfill attributes for commercial end use projects include the following:

- High potential property value as a commercial site. This is largely a function of location;
- High native soil-to-refuse footprint ratio; and
- Older, shallower, mound-type landfills are generally preferred. These conditions result in reduced landfill gas production and settlement concerns.

Case Studies

This section will present brief descriptions of case studies of redevelopment atop closed landfills. As the title suggests, individual case studies will address applications such as golf courses, greenhouses, and other construction. This paper will describe the following projects:

- Jamacha Landfill, a long closed landfill with microturbines installed
- Industry Hills, a golf course development with direct use of the collected landfill gas
- Renaissance Park, another golf course development atop a landfill with gas controls
- Willow Run Farms, a greenhouse atop a landfill with direct use of the gas
- Parkway Center Mall, a shopping center atop a landfill with gas controls
- Westport Office Park, an office building development atop a landfill with gas controls
- Don Kott Ford, an auto dealership atop an old landfill with gas controls
- South Bay Six Drive-In Theatre, a drive-in with structures atop a landfill
- Los Angeles Metro Mall, a proposed mega retail development atop a landfill
- Goodyear Airship Operations Center, a blimp landing field atop a closed landfill
- Montebello Town Square, a shopping center adjacent to a large landfill with gas controls

Jamacha Landfill

The Jamacha Landfill is a small, municipal solid waste landfill located in San Diego, California. The landfill operated from 1960 through 1978, and has been closed for more than a decade. Landfill gas is continuously produced in open and closed solid waste landfills as a product of biological degradation of organic waste. Because Jamacha Landfill is relatively small (less than 1.6 million tons of waste in place) and because the landfill is old, its landfill gas production is relatively low and its methane content is relatively low (37 percent). In addition to methane, the other principal components of landfill gas are carbon dioxide and air. A landfill gas collection and control system had been installed at the Jamacha Landfill in 1995. The system consisted of vertical wells, gas collection piping, a vacuum blower and a flare stack.
As originally constructed in June 2001, the Jamacha microturbine project consisted of the following components:

- interconnection with the flare station to establish the landfill gas supply
- a 60 hp, 200 cfm landfill gas compressor which delivered 80 psig gas
- a refrigeration system which chilled the compressed landfill gas to 40°F to condense moisture and impurities
- four 75 kW Honeywell Power Systems Parallon microturbines
- a propane storage tank to "sweeten" the landfill gas during the first three minutes of start-up

- switchgear
- motor control center for the motors on the compressor skid
- step-up transformer to increase voltage from the generation voltage of 480V to utility line voltage

Because of Honeywell's decision to exit the microturbine business, Honeywell's units were shut down in early November 2001 and were returned to Honeywell for a cash refund. The shutdown occurred after over 2,000 hours of operation without noticeable deterioration in performance.

After an evaluation of what equipment was commercially available, a decision was made to purchase four 70 kW Ingersoll-Rand Power Works microturbines to replace the four Honeywell microturbines. Start-up of the replacement units occurred in January 2002. The units were operating successfully as of February 2002, using the original compressor, switchgear and utility interconnection.

Industry Hills

The Industry Hills Recreation and Conference Center is located on the same development as two of southern California's most prestigious golf courses. The development also contains a conference center, Olympic-sized swimming pool, a tennis complex, equestrian center, laundry facility, and 11-story hotel. The 617 acre site includes 155 acres formerly used for sanitary land filling purposes between 1951 and 1969. The facility is located approximately 10 miles east of downtown Los Angeles, California. About 3.6 million tons of municipal waste were deposited into the landfill, which has an average refuse fill depth of approximately 35 ft.

The LFG management facilities at the project consist of two main systems, with the initial installation in February 1974. The first system prevents the accumulation of methane gas beneath on-site structures, and migration beyond property lines. Migrating LFG is collected and then destroyed at a blower/flare station capable of burning 500 cfm of LFG.

The second gas control system was designed for LFG energy recovery. While this system aids in LFG migration and surface emission control, it also supplies medium Btu fuel for convention center boilers and water heaters for the Olympic-size pool and laundry complex. The LFG process facility compresses and cools the gas to remove free liquids, and is capable of supplying approximately 2,100 MM Btu fuel each month. This saves the City of Industry approximately $10,000 to $15,000 each month in displacing natural gas demands.

Operation and maintenance of the gas system is regulated by strict guidelines from a number of different state and local enforcement agencies. In addition to these strict guidelines, the design engineers have developed numerous operating criteria that present unique challenges to the facility's operators. Some of the major challenges are health and safety, coordination with numerous on-site personnel like security guards and ground maintenance crews, odor control, and maintenance repair and access.

Evidence of the development's success is apparent in the project having received two separate prestigious awards. The facility was awarded the "ASCE Outstanding Civil Engineering Achievement Award" in 1981. In 1997 it received the "SWANA Gold Award for Landfill Gas Projects."

Renaissance Park

Renaissance Park is a community recreation complex constructed atop a closed landfill in Charlotte, North Carolina. Facilities over the former landfill include soccer fields, softball fields, and a tournament level golf course. The City of Charlotte had owned and operated the site as a municipal solid waste landfill since the late 1960s. The landfilling operation was closed in 1986. The landfill comprises several discrete areas totaling approximately 375 acres of landfill footprint.

Several migration control systems were installed subsequent to landfill closure, including a passive LFG venting system around the golf club house, a passive vent trench along the northeast property line, and an active LFG migration control system along York Road (which contains several subterranean utility pathways and has occupied office buildings beyond).

Due to the open air nature of the recreational facilities placed atop the landfill, the original design concept did not entail comprehensive LFG collection through the landfill's interior surface areas. As a result, recreational facilities and other site improvements were left largely unprotected by LFG control systems. Theoretically, the absence of occupied structures atop the landfill proper, mitigated the opportunity for LFG combustion hazards, or other deleterious impacts due to landfill settlement.

In practice, several hazards have developed since the time the recreational facility at Renaissance Park (atop the landfill) was placed in service in the late 1980s. These problems, and their accompanying solutions, are delineated below:

- **Periodic Fire Hazards.** Renaissance Park has experienced periodic ground fires caused by the ignition of LFG emitting through surface cracks. Reports of periodic fires have developed over the years. Normally, LFG dissipates quickly into the atmosphere so that such instances are not anticipated and do not occur. Other precautions have been taken including banning of open air fires and camp-outs atop the closed landfill, for obvious reasons. Continued attentiveness to this matter is required for the future.
- **Fencing.** Chain link fencing is common around the ball fields at Renaissance Park and typically includes galvanized steel pipe for the fencing posts. These posts invariably fill with LFG, and present a potentially hazardous condition. Technicians have monitored methane accumulations in the fence posts to levels approaching 50 percent gas around the soft ball fields at Renaissance Park. As with many such conditions, the chances for ignition or other human hazards are low, unless fencing post caps are intentionally removed by vandals. An easy solution to this problem is to specify that each column fence post not have a hollow interior in which LFG can accumulate.
- **Electric Boxes.** Electric power is most often used for lighting and concession stands at recreational facilities. Panel box explosions have occurred at landfills due to the accumulation of methane entering via underground electrical conduit. Conduit seals should be used between underground conduits and electric panel boxes, to prevent this pathway for LFG migration. Outdoor panel boxes atop the landfill are not normally considered to be in a classified location per the National Electric Code. Hence, conduit seals are not required for the purpose of isolating combustible hazards, but rather they serve as a barrier to block LFG potentially migrating through the conduit.

In 1993, a woman was injured in an explosion at Renaissance Park when she lit a cigarette lighter to find a soccer ball that had rolled under a flood light footer pad. The explosion is believed to have been fueled by LFG entering the void space created by landfill settlement around the footer pad. Several other fires on the golf course, and within an off-site utility trench have also resulted with the ignition of LFG accumulations and emissions.

As a solution, the City of Charlotte responded with an intense investigation of LFG hazards at Renaissance Park. With identification of areas in which combustible gas can accumulate, a remediation program was designed, and is routinely implemented. The key is to avoid the accumulation of combustible gas inside settlement cracks, settlement cavities, and other man-made structures as delineated previously.

Willow Run Farms

Development of greenhouses atop and adjacent to sanitary landfills has been suggested for many years. Energy represents a significant cost of operation for greenhouse installations. The availability of cheap energy from LFG recovery operation can create an opportunity to provide energy to greenhouse operations on a discounted basis. In addition, the settlement and other environmental and technical impacts from sanitary landfills can be better accommodated by most greenhouse operations, than would be the case with other more rigid structures. Still, the opportunity exists for the uncontrolled entry of combustible gas to the greenhouse operation due to its proximity to the landfill. Under these circumstances, the LFG collection system used for energy supply must be examined, and its comprehensive performance ensured for the safe occupancy of the greenhouse operation.

With these conditions as background, Wayne Disposal developed a greenhouse operation known as Willow Run Farms in Belleville, Michigan (Detroit metro area). The greenhouse consists of a 45,000 sq. ft. development, atop a 70-acre closed municipal solid waste landfill cell.

An active LFG extraction system including vertical wells has been installed throughout the 70-acre landfill development. LFG collected from this system is used to generate electricity on year-round basis.

However, the LFG-to-electricity-operation generates revenue at a poor rate of only $0.02 per kW-hour. During winter months when demand for cheap energy is highest from greenhouse operations, part of this fuel is diverted to a medium Btu application of greenhouse heating.

Willow Run Farms has spent more than $500,000 on capital and operating costs associated with the greenhouse operation through its first four years. The investment includes the cost of erecting a one acre, 10-bay greenhouse supplied by Clover Greenhouse of Smyrna, Tennessee. Specialty crops including watercress, chives, basil, osaka red mustard, bib lettuce, and other items are grown in the greenhouse. Growth is enhanced at the Willow Run operation hydroponically, in a medium of water and nutrients. Thanks to this controlled environment, no herbicides or insecticides are needed. Since this is such a highly productive method, the farm is able to grow a crop from seed to package in only 5 to 8 weeks.

Parkway Center Mall

Parkway Center Mall is located in Pittsburgh, Pennsylvania. The site is an existing multi-level shopping mall located to the west of downtown Pittsburgh, on the interstate access between Pittsburgh International Airport and Downtown. The mall has a 200,000 sq. ft. footprint. The mall is located primarily above a former municipal solid waste (MSW) landfill with depths up to 120 ft. The mall itself was constructed on piles ranging in depth from 20 to over 80 ft. A landfill gas management system, including vertical wells and crawl space ventilation, was installed in 1983 and remains successfully operational to this date.

Parkway Center Mall is owned and operated by Kossman Development Company. Kossman was the original developer of the facility, and contracted with an engineer for LFG related services beginning in 1981. The engineer began with a combustible gas investigation of the site. From this investigation, the depth, areal extent, and degree of decomposition of deposited waste was ascertained. In addition, the presence of combustible gas was detected both within the landfill limits, and was found migrating to areas outside the landfill limits to distances exceeding 100 ft.

Subsequently, the engineer conducted a pump test program on behalf of Kossman Development. The intent of this program was to more specifically ascertain the appropriate well spacing and vacuum performance of a proposed vertical gas extraction system. Pump test programs are not always required in the design of active LFG collection and control systems. However, since this system was to be installed in a crawl space under a shopping mall, and since subsequent retrofit of additional gas extraction wells would be particularly challenging, more detailed advance information useful for design of the gas control system was desired. The ensuing pump test program was successful in determining the appropriate well spacings and expected gas system performance.

Subsequently, the engineer designed an LFG extraction system including some 30 vertical wells. Six of these wells were to be located directly under the proposed shopping mall. The balance were located primarily in proposed parking lot areas, to the south of the proposed shopping mall. Together, these vertical gas extraction wells would exert an outward zone-of-influence, to minimize or prevent the upward migration of combustible gases to the crawl space underlying the proposed shopping mall. Vertical gas extraction wells were then connected together with subsurface plastic header lines. These headers were directed to a single blower/vent location. At this location, two separate centrifugal exhausters provide sufficient vacuum and flow capacity to draw gases from the gas extraction wells, through the headers, thence through the blowers, and to a vent pipe located aside the blower building. Gases are then harmlessly vented to the atmosphere. The combustible and malodorous gas content of collected gases has been deemed sufficiently low that flaring of the collected gases was neither possible nor required.

As is the case for any LFG/building control system, the engineer desired both primary and secondary collection systems. Accordingly, a scheme of emergency crawl space ventilation was also proposed for Parkway Center Mall. If the active gas collection system was found to be insufficient to control combustible gas buildup in the crawl space or the mall's occupied space, this crawl space ventilation system could be activated and immediately exhaust the buildup of combustible gases from under the mall. This emergency crawl space ventilation was to be activated only under circumstances of detectible combustible gas buildup in the crawl space below. Based on calculations performed by the design team for the project developer, it was determined that introducing constant and high-rate air changes to the crawl space would place an extraordinary heating load on the mall above. Thus, crawl space ventilation was proposed only as a backup emergency system.

An automated and continuous combustible gas detection system was installed in the crawl space below the mall. In addition, manual checks of combustible gas content using site personnel and combustible gas meters serve as a backup to these continuous monitoring devices. To date, no combustible gas has ever been found to accumulate in the crawl space beneath the mall.

Since installation in 1983, this gas control system has been found to be completely and continuously successful in controlling migrating gases. The mall development has been financed and insured through multiple iterations. In addition, tenants occupying the mall and out-buildings have registered no significant concerns with the presence of combustible gases in the ground below. All proposed and existing tenants are made fully aware of the site conditions. With proper explanation, they appear satisfied that combustible gas control is adequately addressed, and that the site has been made completely safe.

Through the approximate 16 years of continuous operation, the combustible gas control system has been found to be completely effective. In addition, the site developer has characterized the maintenance associated with the combustible gas system to be less than expected. Routine monitoring and inspection of the gas system does occur at minimum monthly intervals at this time. Periodically, replacement of gas control system elements is required. Greater concerns have developed with regard to subsidence at the site (due to the excessive depth of the landfill below the mall). These actions have included:

1. Differential settlement in the mall parking area, which has required repaving and regrading of its surface.

2. Differential settlement which causes tilting of light stands located in the parking area. Periodically, these must be repaired.

3. Periodic repair of utility connections from the mall parking area to the mall structure itself. Since the mall remains at a stable elevation, and adjoining areas are constantly settling, a shearing stress develops on the inter-connection of utilities from outside areas to the mall itself. Repairs must be applied.

4. Access to the building is also a challenge. The integration of site access from the parking area to the mall needs to be continually adjusted to allow for differential settlement as described above.

Westport Office Park

The Westport Office Park is a proposed development currently under construction in Redwood City, California. It is a 20-building, 980,000 sq. ft. project in a park-like setting planned for R&D facilities, office, and biotech applications. The 85-acre site was initially used as a municipal solid waste landfill beginning in the 1940s until 1970. The presence of underlying refuse has created challenging engineering issues for site development, including protection of structures from explosive gases, site settlement, and preservation of the clay liner.

The Westport project is one of the most ambitious projects ever undertaken on a former landfill site. The estimated site development cost of over $100 million makes it the fifth largest project under construction in northern California.

An engineer was retained by the general construction contractor to provide various landfill engineering, permitting, and construction management services. The engineer prepared design plans and specifications for protecting site structures from potential explosive hazards associated with LFG infiltration. Construction observation services were provided thereafter to verify that the protection features were installed per the design plans and regulatory requirements. A comprehensive landscaping and drainage plan was also prepared. The objective of this plan was to protect the landfill cap from water infiltration and root damage, while promoting healthy long-term plant growth in a distressed environment.

Key protection and monitoring features have been designed and incorporated into the development. These include:

- Subfloor membrane, passive gas venting system, and a continuous automated combustible gas sensor network installed in each building.
- Subsurface gas migration barriers installed in site utility corridors.
- A venting system to relieve gas pressure build-up in parking lot areas overlying the deeper portions of the landfill.
- A leachate cut-off trench and subsurface gas venting and monitoring system installed at the development's property line.

Don Kott Ford

One of the earliest combination closed-landfill and commercial use projects was a project built in Carson, California, in 1980. A truck sales and maintenance center was installed atop 9.5 acres of an 18-acre landfill. The landfill operated between 1962 and 1964. It was a 35-ft deep, mound-type landfill. A landfill gas collection system consisting of 14 vertical extraction wells and a flare was installed. The building's structural slab is supported by piles (concrete in steel pipes) which extend to native soil. A 30-mil chlorinated polyethylene (CPE) membrane was installed inside the building's concrete slab. A methane gas detection system was installed in the building to automatically annunciate the presence of methane at 25 percent of its lower explosive limit. The truck sales and maintenance center is currently in operation. The engineer continues to provide landfill gas operation, maintenance, and monitoring services at this site.

South Bay Six Drive-In Theater

The South Bay Six Drive-In Theater was constructed in Carson, California, in 1981. The drive-in was built atop a 24-acre, 50-ft deep, mound-type landfill. The landfill was open between 1964 and 1971.

A landfill gas collection system consisting of 50 vertical extraction wells and a flare station was installed to control surface emissions and to aid in protection of on-site buildings. The on-site buildings included a large concession building located in the center of the site. The concession building's structural concrete slab is supported by concrete piles which extend to native soil. The building was equipped with a 30-mil CPE membrane inside the structural concrete slab. Gas sampling probes were installed under the slab and were connected by PVC pipe to sample valve boxes surrounding the building. A methane gas detection system was installed in the concession building to automatically annunciate the presence of methane at 25 percent of its lower explosive limit. The main roadways on the site are asphalt and the parking areas are paved with rock and oil.

The engineer designed and installed landfill gas collection and building protection systems for this project, and in doing so further established the firm's reputation in the areas of landfill gas control and in closed landfill beneficial use. The engineer operated the landfill gas collection system into the mid-1990s, at which time the drive-in closed for economic reasons.

Los Angeles Metro Mall

The Cal-Compact Landfill is a 157-acre landfill located in Carson, California, adjacent to Interstate 405 (San Diego Freeway) just south of Los Angeles. Its prime location has led to several proposals for commercial development. A recent proposal called for the development of an 810,000 sq. ft. shopping center on top of the landfill.

The landfill is a mound-type landfill with an average refuse depth of 40 ft. The design of the mall calls for over 3,000 piles to support the building. The engineer designed the landfill gas collection and building protection systems for this project. The engineer completed design work on this project in 1997. The landfill gas collection system incorporated vertical extraction wells, a network of horizontal collectors, and a 1,500 scfm flare. The building protection system consists of passive horizontal vents above the landfill cap and below a membrane, a membrane below the structural slab, and methane sensors inside the buildings.

The Metro Mall project did not proceed due to the developer's problems in securing financing. This project has been mentioned herein because it illustrates that very large retail space beneficial use projects are under consideration at closed landfills.

Shoreline Park and Amphitheater

The City of Mountainview, California, has converted its landfill into a mixed-use recreational facility. The mound-type landfill is located on San Francisco Bay. Facilities within Shoreline Park include a golf course, jogging trails, a sailing lake and an open-air amphitheater. The amphitheater has a seating capacity of 8,000 and is partially covered with canvas roofing. The principal protective feature for the amphitheater is a landfill gas collection system consisting of vertical extraction wells and a flare. The city maintains a landfill gas collection system throughout the balance of the landfill. The engineer has operated the amphitheater's landfill gas collection system since 1986.

Goodyear Airship Operations Center
The Goodyear Airship Operations Center in Carson, California represents a somewhat unusual landfill end use. The facility serves as the western landing field for the Goodyear blimp. The facility includes a 2,600 sq. ft. office and maintenance center located on native soil. The landing field itself is over refuse on a small portion of a 348-acre landfill that used the trench-fill method of disposal. The landfill operated between 1949 and 1959. The depth of refuse generally varies from 10 to 30 ft.

A landfill gas collection system was not installed at this site. The office and maintenance center are protected by a membrane and a methane detection system designed by the engineer. The facility was installed in 1984.

Montebello Town Square
A decision was made in 1990 to construct a 400,000 sq. ft. shopping plaza immediately adjacent to the 145-acre Operating Industries, Inc. (OII) landfill in Montebello, California. The OII landfill is a mound-type landfill on top of valley-fill landfill segments. The OII landfill is a Superfund site which contains 29 million tons of municipal solid waste and immediately abuts the property used for the shopping center. One of the largest buildings in the shopping center is only 200 feet from the edge of refuse, and the refuse is as much as 100 feet below the level of the building slab within 500 feet of one of the larger buildings. At the time the shopping center was constructed, the OII landfill had a partial, aged landfill gas collection system, and landfill gas was migrating off site. The property underlying the landfill and the shopping center is not under common ownership; however, the proximity of the refuse to the development provides a good illustration of building protection measures which can be taken if a development is located only on the native soil portion of a landfill parcel.
The engineer designed a system consisting of:

- Eight in-soil landfill gas extraction wells and a 500 scfm flare. The wells are located between the landfill and the shopping center, on property owned by the shopping center, and they create a barrier to landfill gas migration.
- Eleven landfill gas migration monitoring wells are located between the extraction wells and the buildings to monitor the effectiveness of the landfill gas extraction system.
- Building protection consisting of an underslab 80-mil high density polyethylene (HDPE) liner and subfloor passive venting system.
- A novel automated methane sensor system, which relies on a detection system installed between the slab and the membrane. The subslab monitoring provision eliminated the need to install sensors inside the buildings.

The landfill gas migration control system went into operation in 1990, and the last building was installed in 1994. Under a separate engagement for the owner of the OII Landfill in 1999, the engineer designed comprehensive improvements to the OII Landfill's landfill gas collection and control system. When placed in service in 2000, the upgraded system arrested landfill gas migration at its source, and the shopping center's migration control extraction wells and flare were shut down due to lack of landfill gas. The shopping center's landfill gas migration control system has been placed in a standby mode, and the migration and building monitoring components remain in service.

Conclusion

Closed landfills have been successfully developed into productive land uses. However, the challenges inherent in development of a closed landfill are substantial. Experience has shown that technical challenges such as settlement, deep foundations, gas protection, and health and safety issues can be met. Legal liability challenges continue to present impediments to landfill redevelopment. However, recent brownfield policy initiatives at the federal and state levels, coupled with increasing experience on the part of national lending institutions, suggest that such impediments also can be overcome.