Landfill Gas: An Asset & a Liability

While the technological means to collect, process and use landfill gas currently exists, future technological gains will only serve to make it more economically feasible and environmentally friendly.

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Landfill gas is used in many ways and there are many approaches to regulating its release into the atmosphere. As with most alternative energy sources, landfill gas (LFG) presents many technical and environmental challenges to be overcome before its potential as a long-term renewable energy source can be fully realized.

Every day in the United States, each man, woman and child produce approximately 4.5 pounds of solid waste. The majority of this waste is disposed in landfills. As the solid waste decomposes, landfill gas is produced.

Landfill Gas & Global Warming

Why should there be any concern about landfill gas? Landfill gas is a concern because it is comprised of two main components: methane and carbon dioxide. Research of landfill decomposition and gas generation has produced different descriptions of the process for producing methane and carbon dioxide. The three basic phases of biological decomposition are: aerobic, anaerobic acid and methanogenic.

The first phase in the cycle of decomposition is the aerobic phase. It begins when the waste is first placed on the landfill and there is plenty of oxygen present. Oxygen-utilizing microorganisms degrade the readily decomposable organic material, primarily down to carbon dioxide, heat and cell mass. This stage continues until the oxygen is depleted, which can range from a few days to a month or more, depending on oxygen availability and landfill covering.

The second phase in the cycle of decomposition is the anaerobic acid phase. It begins when the oxygen supply within the waste is depleted to the extent that aerobic activity is no longer possible. Anaerobic fermentative and hydrolytic microorganisms then dominate and decompose the next most available waste components: cellulose, fat and proteins. These substrates are metabolized into soluble sugars, amino acids, carboxylic acids, glycerol, alcohols, carbon dioxide and hydrogen.

The third phase in the cycle of decomposition is the methanogenic phase. Typically, there are three main groups of microorganisms that comprise this phase. First, there are fermentative and hydrolytic microorganisms, next are the proton-reducing acetogens and lastly the methanogens. The methanogens use what the other microorganisms create to produce methane and carbon dioxide. All three of these microorganism groups rely on each other to remove inhibitory compounds to produce useable substrate for the next microorganism group — the basic cycle of "decomposition to gas."

Methane and carbon dioxide have been determined to contribute to global warming. Even if you are not a believer in global warming, federal governmental policy has been affected and, therefore, so has every citizen of the United States. Landfill gas emissions by nature pollute the air and contribute to the existence of smog in the atmosphere. The generated methane in LFG is a potent "greenhouse" gas that has an estimated global warming effect of twenty times that of carbon dioxide.

Former President Clinton's Climate Change Action Plan put into policy the need to reduce greenhouse gases. (Greenhouse gases are defined as those gases that contribute to global warming.) Since methane and carbon dioxide fall into this category, the control of landfill gas has become very important to public policy. It is also known that landfills have been determined to be the largest source of man-made methane and that controlling landfill emissions is the most cost-effective method for reducing greenhouse gas emissions in the United States.

A Rising Hazard

Landfill gas presents safety and environmental hazards. Everyone has smelled it, and undoubtedly neighboring residents of landfill sites can attest that LFGs are the source of foul-smelling odors. It is the decomposition of organic solid waste in a landfill that produces the landfill gas. While the main components of LFG are methane and carbon dioxide, trace elements of volatile organic compounds (VOCs) and non-methane organic compounds (NMOCs) are also found in LFG. NMOCs usually make up less than 1 percent of landfill gas. Combined together, the components that comprise LFG are toxic to humans, soil and groundwater. Posing a further concern, LFG naturally migrates through soil and other landfill mediums into the atmosphere, groundwater or into structures located on or near landfills. This migration can be very dangerous to humans, animals and vegetation. Once it invades a structure, the methane contained within the LFG presents a serious fire and/or explosive hazard.

Now, by federal law, LFG migration must be restricted to protect property and to ensure public health and safety. Another environmental concern is that as the LFG migrates to the surface of adjacent lands, it displaces gases such as oxygen in the soil. This migration causes trees and other plantlife to die. To mitigate this effect, jurisdictions throughout the United States now require landfill operators/owners to reduce reactive organic gas emissions. In doing so, landfill owners contribute across the nation to the improvement of air quality, while meeting the requirements of federally mandated regulations.

Landfill Gas Regulations

A number of regulations govern LFGs. The Resource Conservation and Recovery Act (RCRA) — first enacted in 1970, amended in the 1980s and also in the 1990s — institutes landfill site design and performance standards. In 1996, the RCRA was again amended incorporating Subtitle D, which requires the monitoring of landfill gas and establishes performance standards for combustible gas migration control. Landfill owners/operators are required to establish an LFG-monitoring program. This program should also include testing for the subsurface migration of combustible gases on a quarterly basis. In addition, Subtitle D requires landfill owners/operators to maintain total combustible gas concentrations to under 5 percent in soil located at the property line, and under 1.25 percent in facility structures. Furthermore, Subtitle D requires mitigation for all gas hazards not in compliance with established performance standards. Typically, the mitigation involves the implementation of either a "passive" or "active" gas recovery system.

The New Source Performance Standards and the associated Emissions Guidelines (NSPS/EG), proposed in 1991 and enacted in

1996, were created to monitor and limit such things as landfill gas NMOC emissions emanating from new landfill sites and to work in conjunction with Subtitle D. NSPS requires that LFG testing and collection systems be installed at many sites, even those that otherwise are in compliance with RCRA Subtitle D. Newly developed landfills are now responsible for a host of monitoring, testing and landfill gas processing activities depending on the type and size of the landfill. NSPS requires that landfill owners/operators estimate total LFG emissions using sophisticated gas models, laboratory analyses and gas pump tests. Landfill owners/operators also need to install comprehensive gas-collection systems throughout the landfill at any site shown to have high emissions of NMOCs. These systems include, but are not limited to, the installation of vertical gas wells, horizontal gas trenches or both. Figure 1 shows a typical LFG recovery well.

The goals are to minimize off-site gas migration, to optimize the collection of methane and NMOCs, and to achieve the lowest attainable emissions rate. The guidelines also stipulate when the new source of emissions is required to install an "active" gas collection system, when to monitor and what the acceptable limits are for gases escaping to the atmosphere.

The U.S. Environmental Protection Agency (EPA) estimates that close to one thousand landfills across the country are affected by its new regulations. The latest EPA regulations limit the allowable VOCs in LFG emissions. VOCs interact with nitrous oxides to form ozone, a primary cause of smog. The EPA has proposed control of surface LFG emissions under the Clean Air Act (CAA) of 1990. The Clean Air Act imposes guidelines for new sources of landfill gas at municipal solid waste sites. In general, the act requires pre-construction permitting, new source reviews based on predicted LFG generation, compliance with the NSPS Emissions Guidelines for NMOCs and the implementation of the maximum available gas control technology. Implementing these mandates is no short order, and makes operating and owning a landfill a complex undertaking. Lastly, landfill owners have

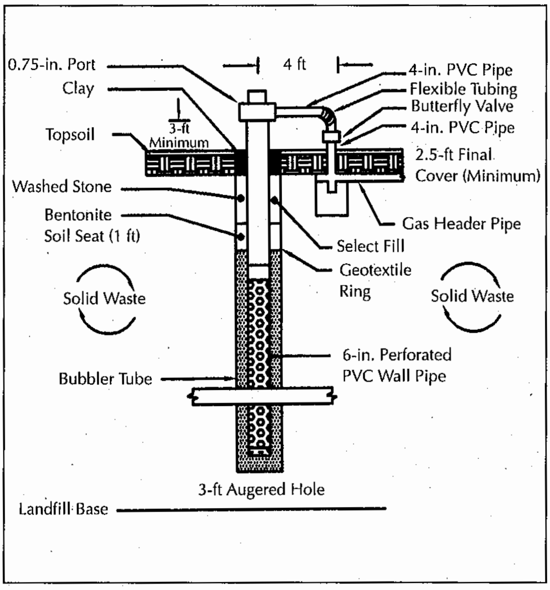

FIGURE 1. A typical LFG recovery well.

to operate and maintain records for such landfill gas systems throughout, and beyond, the life of the landfill. The implementation of these EPA regulations requires close to one thousand landfills nationwide to control LFG emissions entering the atmosphere due to decomposing garbage.

Regulation of LFG is predicated on the fact that it is harmful if left uncontrolled. Therefore, these regulations reflect positive steps to effectively control a long-term liability. The regulation's underlying intent is for the LFG to be collected and utilized, potentially providing increased economic and community benefits.

Converting a Liability to an Asset

The fact that LFG must be controlled promotes exploration of technological advances that can allow this liability to be converted into an asset. According to the EPA, 1 million tons of waste "in-place" typically generates around 300 cubic feet per minute (cfm) of landfill gas that could be used to generate 7,000,000 kilowatt hours (kWh) of electricity per year. This 7,000,000 kWh of electricity is capable of powering approximately 700 homes for one year. Utilization of 300 cfm/year of LFG yields an approximate equivalent reduction in greenhouse gases to that of removing 6,100 cars

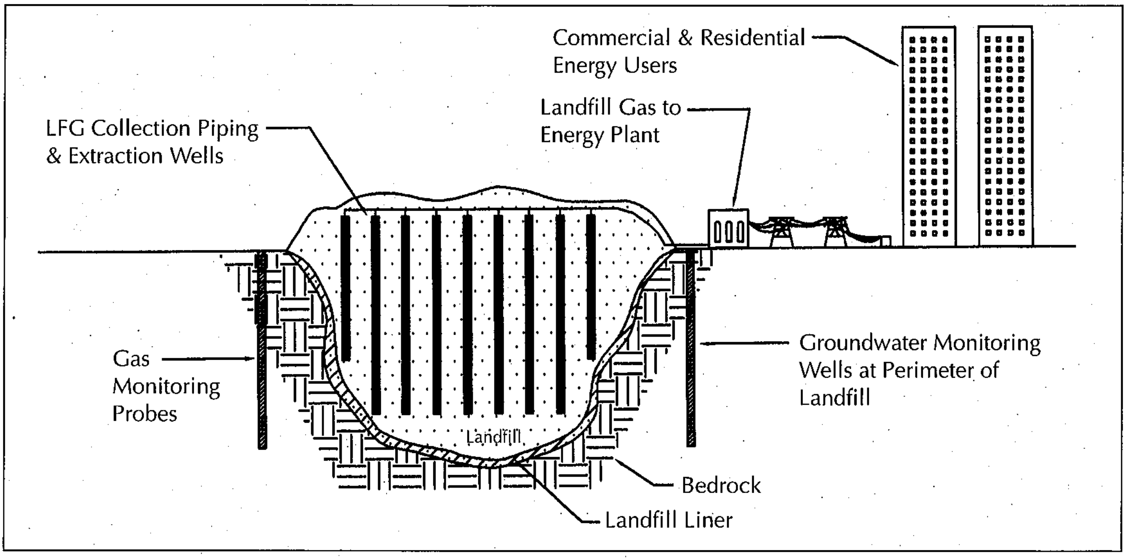

FIGURE 2. A typical elevation of a LFG recovery system.

from the road for one year. Correspondingly, using 300 cfm/year of LFG produces similar greenhouse gas impacts as planting 8,300 acres of trees.

Furthermore, as of June 1999, over 270 LFG recovery and utilization projects were operating in the United States, 15 of which are in the state of Massachusetts. Moreover, the EPA estimates that about 500 other landfill sites present attractive opportunities for project development. These sites are landfills that generate quantities of LFG that could be commercially exploited. Presently, LFG-to-energy projects (LFGTE) have prevented the release of 1.5 million metric tons of carbon equivalent (MMTCE, the basic unit of measure for greenhouse gases) into the atmosphere. Figure 2 shows a typical LFGTE recovery system.

These LFGTE projects have permanently eliminated the equivalent pollution from 1.1 million cars. Interestingly, some of the reasons behind the low percentage of landfill sites utilizing LFG is attributed to the limited research, and quantification of gas generation in actual field settings. These facts contribute to negative or unattractive investment perceptions of LFG energy projects. As a whole, most investors view these potential projects as being risky. Therefore, gaining information through further research and refinement of LFG and its process requirements will lower risk factors for future LFGTE project investments.

The capture and utilization of LFGs for the generation of electrical and/or heat energy is a great concept; however, improvements must be made on many frontiers before this idea can become implemented on a widespread basis. Federally sponsored programs, funding, subsidizing and tax credits have given life to the concept, but there are limitations to these programs such as the time needed to implement these programs and the necssary federal financial support to keep these programs going.

Another consideration is that the methane content in LFG varies from site to site. Some sites generate LFG with 20 to 30 percent methane, and others from 40 to 50 percent. Methane content depends on many factors and characteristics associated with the landfill's waste diversity, location and climate. If the goal is to maximize the use of LFG, there is a need to design new landfills that will consistently generate LFG with at least 50 percent methane content. Creating this type of performance would need to be specifically tailored into the design of each site. Such performance would be a basic requirement due to the fact that any equipment manufactured specifically for LFG combustion must be standardized like all other fuel-burning equip-

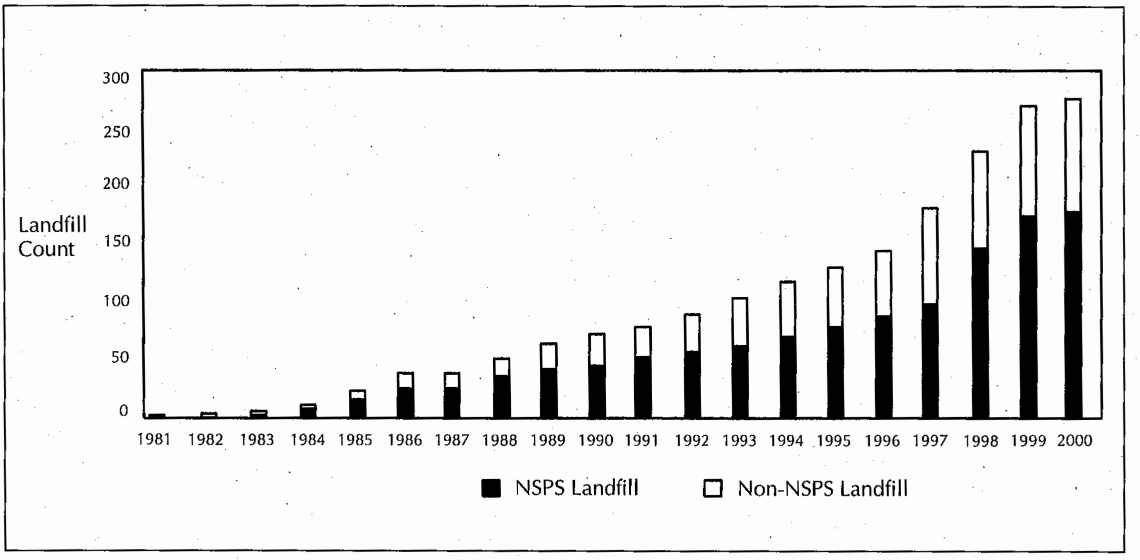

FIGURE 3. Growth in LFGTE project development.

ment. In addition, equipment will need to have the ability to withstand LFG's corrosive nature. NMOCs, when combusted, often combine with other chemicals contained in LFG, forming dioxins. These dioxins are very dangerous and, therefore, warrant the effective "scrubbing or cleaning" of LFG before combustion. If these key drivers cannot be achieved, then economics and market conditions dictate that LFGTE projects will never go to mass production. Furthermore, a fully integrated approach to incorporating the latest knowledge and technology will be required in the design of landfills to achieve a high-quality 50 percent methane LFG. This type of comprehensive design will include proven methods of methanogenic enhancements. Enhancements include the addition of moisture in the landfill or leachate recirculation, landfill phasing and earlier collection of gas. The utilization and distribution of added moisture in the decomposing waste is preferably accomplished by recirculating the leachate generated by the landfill.

However, another alternative is wetting the waste at the time of placement, prior to capping. Leachate and/or added moisture properly distributed throughout the decomposing waste can significantly boost methanogenic processes and the production of methane gas. However, there are technical and environmental challenges associated with adding moisture (leachate) into the landfill that must be overcome. Therefore, if this methanogenic enhancement approach is used, an advanced leachate/moisture control system will inevitably be a basic requirement. Indirect methanogenic enhancements can involve the thorough planning and phasing of cell completion (cells are sections or areas that comprise the landfill), along with the installation of intermediate and/or final covers for the waste in each landfill cell. Phasing the construction of each cell within the landfill and the type of covering installed upon cell completion impact the aerobic and anaerobic decomposition of the waste, which ultimately affects the capacity of the landfill to generate methane and LFG. Additional gas can be collected if systems are installed when construction of each landfill cell begins, continuing until the landfill is completed.

Moreover, technological integration will allow the increase in LFG flow and quality to be captured and utilized. Increasing LFG composition to 50 percent methane (a quality level approaching utility grade) will require that gas enhancements are in place and that collection systems are maximized. Presently, landfills do not generate enough LFG to gather the attention of major utilities, and to receive their commitment and capital for utilization proj-

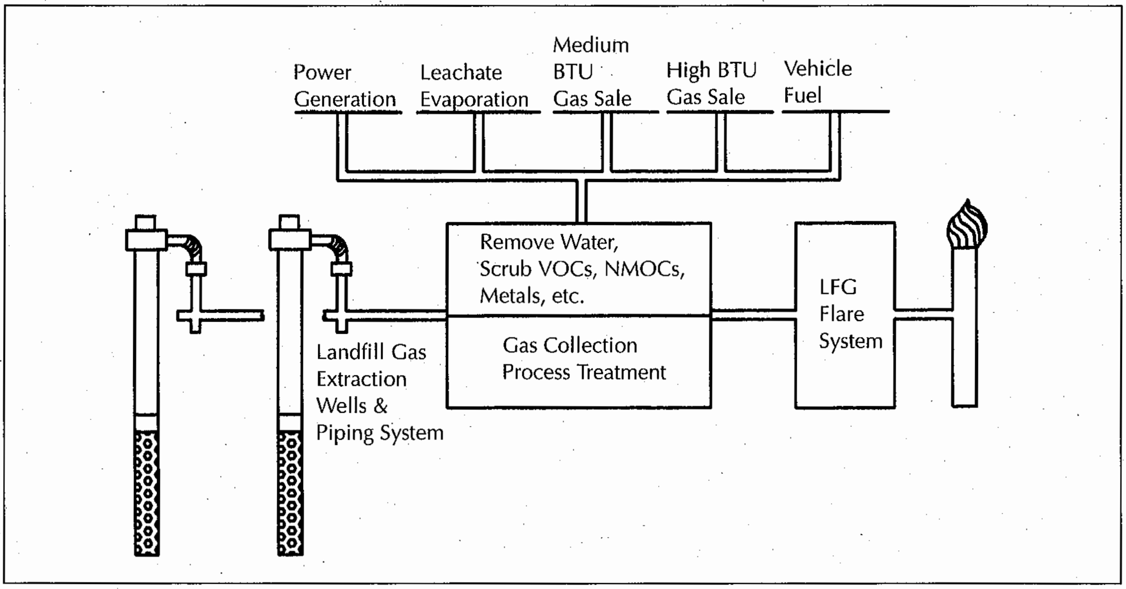

FIGURE 4. Options for LFG use.

ects. This lack of attention is due to the intrinsic nature of landfills — which generate gas in a non-linear fashion over their surface area. This performance characteristic leads to the economic installation of wells and/or trenches that will bring the landfill into emissions conformance. Historically, the focus has been on control and conformance, as opposed to a concept of total site gas collection. However, if the production of methane is enhanced, a greater number of wells and trenches throughout the landfill would be required for increased control. This situation demands another approach to efficiently collecting LFG. Even if the goal of a specific site was not to boost the methane production, but to speed up and condense the LFG production cycle, better control of landfill emissions through improved collection system design can and should be achieved.

Furthermore, with more robust gas collection systems capable of collecting a higher percentage of the total emitted LFG per site, the likelihood of reducing greenhouse gas emissions would increase along with a potential increase in the development of LFG energy projects. Presently, a limited number of local and state governments are discovering that small LFG combustion systems are supplying electrical energy, generating notable revenues and reducing local electrical utility demand. If the LFG production and collection processes are further refined, the overall result would be lower air pollution, an increase in energy generation and a reduction in an environmental liability. However, these concepts for environmental betterment and safety should never be a substitute for the reduction of generated waste by individuals, communities and states. Figure 3 shows the growth in LFGTE project development.

The Utilization Process

LFG is not the same as natural gas or methane. Nor is the combustion of LFG a true "green energy" concept, or one without its environmental concerns. However, until source reduction becomes firmly grasped and implemented by society, LFG will be continuously generated and, therefore, continue to be a candidate for use in energy generation. In terms of energy content, LFG is considered to be a medium-British thermal unit (BTU) gas. When methane gas concentrations in LFG is greater than 35 percent, LFG is economically justified to be recovered for utilization. If the landfill gas contains close to 50 percent methane, it will likely produce approximately 500 BTUs per cubic foot. In comparison, natural gas produces approximately 1,000 BTUs per cubic foot. Additionally, natural gas is approximately 80 to 99 percent methane, with the remainder being mostly other hydrocarbons (ethane, propane, butane, etc.) as well as some nitrogen, oxygen, water, carbon dioxide, sulfur and various contaminants.

Therefore, the combustion of LFG in applications such as "on-site" cogeneration is feasible, but there is a need to increase the methane content in the LFG. Other options for LFG include (see Figure 4):

- Flare it;
- Use it in boilers to make steam/heat;
- Use it in internal combustion engines to make electricity;
- Use it in gas turbines to make electricity;
- Use it in fuel cells to make electricity;
- Convert the methane to methyl alcohol; and
- Clean it up enough for industrial or utility use.

Currently, LFG is being used to fuel boilers to generate steam in industrial applications. LFG use in boilers is an economical option. Boilers produce heat energy, not electricity. Additionally, boilers are generally less sensitive to LFG contaminants and, therefore, require less scrubbing or cleaning of the gas prior to use than other alternatives. Furthermore, boilers have the lowest NO_X and carbon monoxide emissions of the combustion technologies.

However, the piping of LFG continues to be a challenge to existing technology due to corrositivity. Piping technology and materials will need to advance in order to maintain integrity and satisfy environmental specifications before becoming standardized. LFG is also used in combination with other fuels in industrial applications, exemplifying cost-effective uses that can reduce fuel oil dependency. Moreover, direct use of LFG does not require large capital investments for equipment. Because there is little difference generating electricity using LFG in lieu of natural gas or diesel fuel, private industries have been refining the use of landfill gas in their equipment. However, unlike natural gas or diesel fuel, both of which are readily useable, LFG requires gas processing and equipment monitoring. Since LFG has an innate corrosive nature, processing and monitoring are absolutely necessary to ensure safety to equipment and personnel. The gas is corrosive due to its content of acids, VOCs and NMOCs.

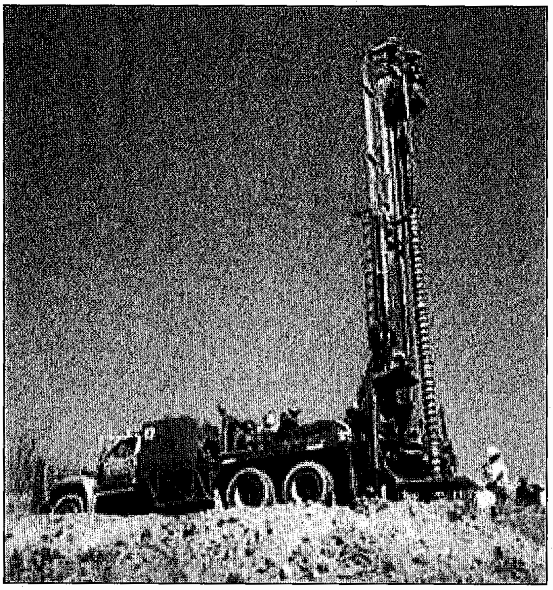

FIGURE 5. Drill rig for gas well installation.

In general, an LFGTE project is comprised of three major components. First, there is a gas collection system, which gathers the LFG being produced within the landfill. The landfill gas is typically collected in a series of interconnected vertical wells located throughout the landfill (see Figure 5). Horizontal underground trenches can also be used to recover LFG as layers of the landfill are added. The quantity and arrangement of wells depends on specific landfill aspects such as volume, density, geometry and collected field data. The wells are constructed by drilling holes into the landfill, to within 5 to 15 feet from the landfill's liner. After the drilling is completed, perforated plastic pipes are inserted into the well holes. The wells are connected by a series of pipes leading to larger header pipes that transfer the gas to the processing and conversion stations. Typically, the piping system is under a partial vacuum created by blowers or fans at the processing station, creating an active collection system. Fan and blower size, along with generated gas pressure will vary accord-

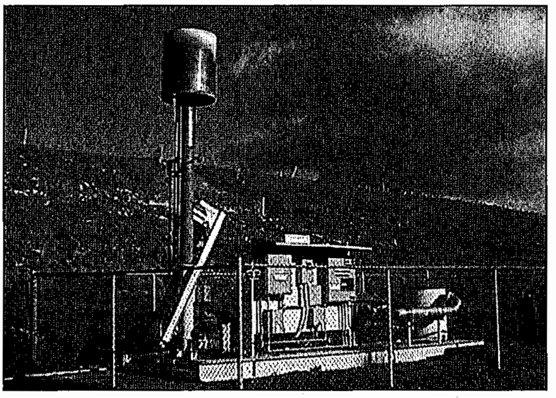

FIGURE 6. A typical "candlestick" gas flare installation for the combustion of landfill gas.

ing to system design, gas flow criteria and owner requirements. Passive collection systems do not utilize blowers and fans, and rely on generated gas pressure in the piping system to reach the point of discharge or flaring.

Next, the collected LFG enters the gas processing and conversion component. It is here that the LFG is cleaned and converted into electrical or heat energy (steam). Typically, the gas needs to be dried and filtered before conversion. Filtering removes foreign particles and the drying removes the high content of water suspended in the gas stream. Typically, LFG is saturated with water, which often creates condensate. The condensate can be collected using traps or knockout drums, and can be either directed back into the landfill or piped into the leachate collection system. After moisture removal, additional gas processing may involve the use of refrigerators or absorbers, such as activated carbon filters, to remove trace contaminants. If the LFG is to be liquefied for use as fuel in vehicles, further processing takes place at this time. LFG used in internal combustion engines for on-site cogeneration typically converts the gas into salable electricity and steam. Understandably, economics drive most of these projects and if conversion equipment is not cost effective, or if the landfill does not generate sufficient LFG, a gas flaring system will be installed to burn the gas (see Figure 6).

The interconnection equipment component, which delivers the energy from the LFGTE project to the end user, must also be considered. After the LFG is converted to electricity and/or steam, dedicated lines deliver the electricity and steam to utilities and municipalities. Interconnection usually includes metering equipment and system protection equipment. System protection equipment provides the interconnection equipment with emergency shutdown capabilities to prevent damage and ensure personnel safety.

An Example of LFG Utilization

In North Carolina, a boiler in a pharmaceutical plant utilizing LFG as its primary fuel generates steam at an average rate of 24,000 pounds (11,000 kilograms) per hour. The energy conversion system uses LFG collected from a city-owned landfill. The local utility, along with private developers, invested $1.6 million in the project. The developers' annual gross revenue from steam sales ranges from $450,000 to $500,000, and the city that owns the landfill receives annual royalties of $65,000 to $75,000 above operating and maintenance costs. The project — a success for the stakeholders as well as a benefit to the host city — is just one of many examples of LFGTE projects creating an asset out of a liability. In addition, this project illustrates the success that can be reached by maximizing partnerships between the public and private sector.

Energy Research on LFG

The U.S. Department of Energy (DOE) funds research on landfill gas with the goal of overcoming barriers to commercialization. In one study, which began in the early 1990s, researchers at the U.S. Department of Energy's Argonne National Laboratory began researching LFG generation, migration and emissions. Field studies included addressing the landfill methane balance — *i.e.*, how methane generated by micro-organisms is apportioned into:

- Methane recoverable by a commercial system;
- Methane emitted into the atmosphere;
- Methane migrated laterally; and,
- Methane converted to carbon dioxide by bacteria in landfill cover material.

DOE LFG projects are field based to achieve a better understanding of LFG processes and also to develop useful techniques for monitoring those processes in field settings. Issues the DOE considers include the LFG collection and control requirements as well as the required post-closure landfill monitoring. If the landfills and the generated gases must be controlled and monitored, then the possibility of selling the processed gas to a customer might help offset costs.

The goal is to develop opportunities for the vast number of existing landfills for direct use of LFG in gas-fired boilers near landfill sites. In addition, existing commercial projects of this type include oil refineries, food-processing plants and projects in other energy-intensive industries such as hotel or hospital complexes, junior colleges and greenhouses.

Expanded Government LFG Programs

The following expansions to federal LFG programs have already begun as part of former President Clinton's Global Climate Change Action Plan. The DOE is charged with expanding research, development and demonstration (RD&D) technologies to recover and use methane from landfills. The DOE program currently has:

- Developed a practical guide to assist public and private landfill owners in the design, construction, implementation and operation of successful LFG recovery and utilization programs.
- Developed and demonstrated efficient and economic processes for increasing the recovery of energy from landfills, thereby decreasing U.S. dependence on nonrenewable energy sources.
- Created joint cooperative RD&D projects between federal, state, industry and other stakeholders to remove technical impediments and other barriers to implementation of enhanced LFG recovery and utilization programs.

In additional, the EPA is responsible for expanding the current Landfill Methane Outreach Program (LMOP), which was instituted in 1994 to encourage landfill owners to capture methane that would otherwise be emitted to the atmosphere and to use it to produce electricity or to sell it as a medium-BTU gas. The EPA outreach program:

- Operates a telephone assistance service for questions regarding the collection, control and use of LFG.
- Provides sample requests for proposals (RFPs) to landfill owners/operators, utilities, state regulators and others that can use these samples in starting up LFG collection and utilization projects.
- Releases case study reports on landfill successes to raise awareness of emission reduction potential.
- Organizes state and regional workshops on landfill energy recovery opportunities.
- Initiates site visits to develop feasibility analyses of project opportunities.

An LFG Proposition

With federal LFG regulations requiring many landfills across the country to collect and control LFG emissions, LFGTE projects may prove to be more than beneficial to the environment. In the early 1990s the EPA qualified some of these bioenergy projects for a 1.5-cent-per-kWh Renewable Energy Production Incentive under the federal Energy Policy Act of 1992, where profits from projects significantly benefited the host communities.

On January 27, 2000, former President Clinton announced the Bioenergy and Bioproducts Tax Incentives. These tax incentives included the Landfill Gas Tax Credit. The tax proposal adds a 1.5-cent-per-kWh credit for electricity produced from landfills not subject to the EPA's NSPS/EG and a 1.0-cent-per-kWh credit for landfills subject to NSPS/EG, for five years. Qualified facilities would be those placed in service after December 31, 2000, and before January 1, 2006.

However, the future will require a greater degree of integration and maximization of technology. The production of methane gas in a landfill can be increased through increased moisture and moisture flow in the solid waste. In addition, the overall composition and phasing of the waste can significantly impact decomposition and methane generation. However, it must be noted that leachate from the landfill and LFG migration into water resources can pose a serious health hazard. Therefore, it is clear that landfill design should continue to evolve. Furthermore, there is considerable latitude for integrating the landfill "system" so that major environmental hazards such as gas and leachate generated from the landfill are converted into assets.

The design of future landfills must consider the continuation of benefits to the host community long after closure. Present policy initiatives — which are acting as a "jump start" for the still-developing LFG industry — will foster technological developments that will significantly improve the economic dynamics concerning the collection, processing and utilization of LFG.

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