PDHonline Course C435 (4 PDH)

Developing LFG to Energy Projects

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1. Landfill Gas Energy Basics

Chapter Overview

Harnessing the power of landfill gas (LFG) energy provides environmental and economic benefits to landfills, energy users, and the community. In particular, LFG energy projects:

- Reduce emissions of greenhouse gases that contribute to global climate change.
- Offset the use of non-renewable resources, such as coal, oil, and natural gas.
- Help improve local air quality.
- Provide revenues for landfills and energy cost savings for users of LFG energy.
- Create jobs and economic benefits for communities and businesses.

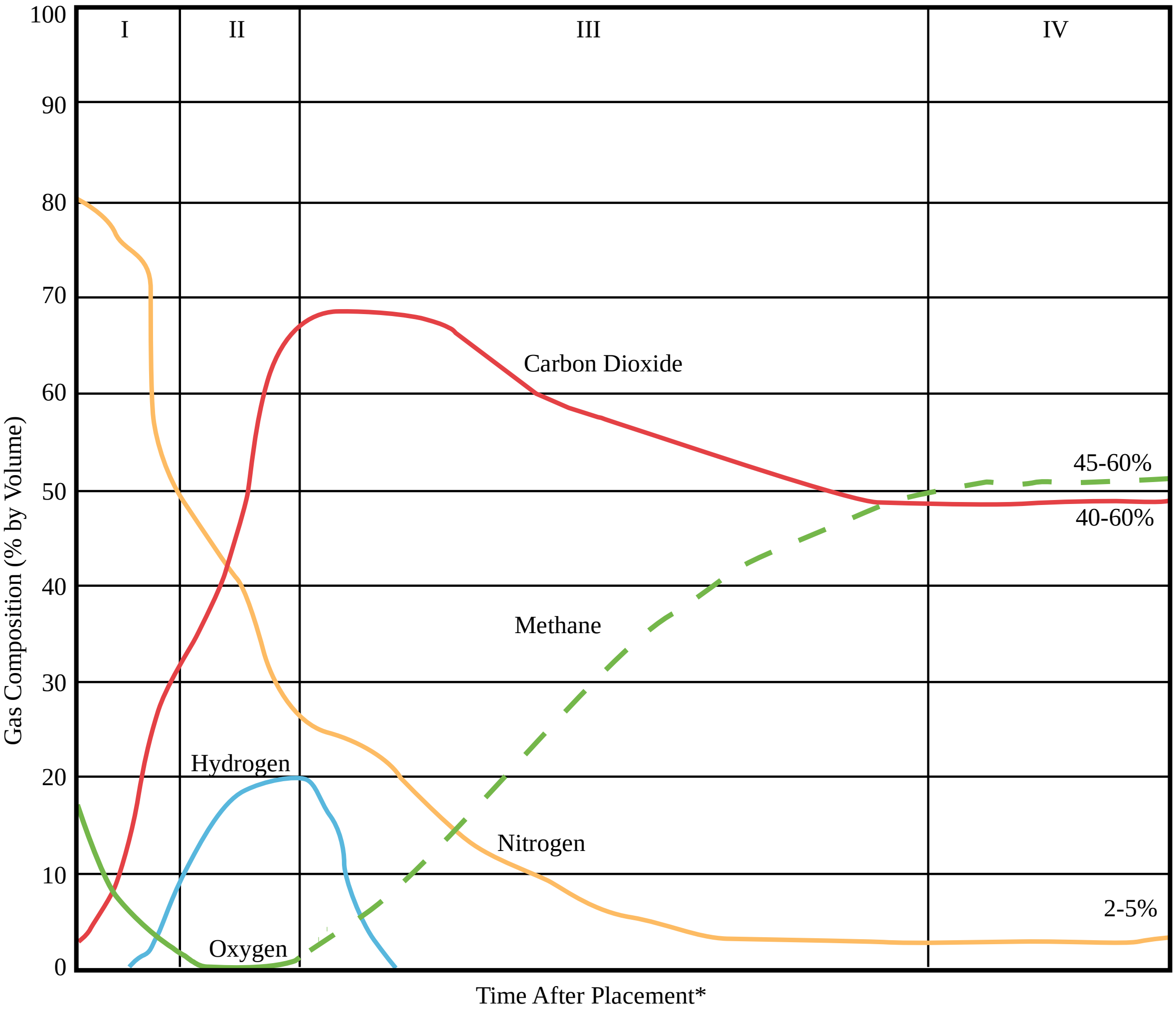
Landfill owners, energy service providers, businesses, state agencies, local governments, communities, and other stakeholders interested in developing this valuable resource can work together to develop successful LFG energy projects. The EPA Landfill Methane Outreach Program (LMOP) encourages and facilitates the development of environmentally and economically sound LFG energy projects by partnering with stakeholders and providing a variety of information, tools, and services.

This chapter provides a brief description of the source and characteristics of LFG and an overview of the basics of LFG collection, treatment, and use in energy recovery systems. This chapter also discusses the status of LFG energy in the United States and the benefits of LFG energy projects. It presents the basic steps of developing an LFG energy project along with descriptions of and links to the information, tools, and resources available from LMOP that may be helpful in LFG energy project development.

1.1 What Is LFG?

LFG is a natural byproduct of the decomposition of organic material in municipal solid waste (MSW) in anaerobic conditions. LFG contains roughly 50 percent methane and 50 percent carbon dioxide, with less than 1 percent non-methane organic compounds and trace amounts of inorganic compounds. When waste is first deposited in a landfill, it undergoes an aerobic (i.e., with oxygen) decomposition stage during which little methane is generated. Then, typically within less than a year, anaerobic (i.e., without oxygen) conditions are established and methane-producing bacteria decompose the waste and produce methane and carbon dioxide (as shown in Figure 1-1). Methane is a potent greenhouse (i.e., heat trapping) gas — over 20 times more potent than carbon dioxide. Landfills are the second largest human-caused source of methane in the United States, accounting for nearly 23 percent of U.S. methane emissions in 2006. For more information about national greenhouse gas emissions from landfills and other sources, see the U.S. Greenhouse Gas Inventory Report.

Figure 1-1. Changes in Typical LFG Composition After Waste Placement[1]



Phases

I. Aerobic
II. Anaerobic, Non-Methanogenic
III. Anaerobic, Methanogenic, Unsteady
IV. Anaerobic, Methanogenic, Steady

* Time scale (total time and phase duration) of gas generation varies with landfill conditions (e.g., waste composition and anaerobic state), but phase IV is generally reached in less than one year.

[1] Figure adapted from ATSDR 2008. Chapter 2: Landfill Gas Basics. In *Landfill Gas Primer - An Overview for Environmental Health Professionals.* Figure 2-1, p. 6. http://www.atsdr.cdc.gov/HAC/landfill/PDFs/Landfill_2001_ch2mod.pdf

Approximately 254 million tons of MSW were generated in the United States in 2007, with 54 percent of that deposited in landfills.[2] One million tons of MSW produces roughly 432,000 cubic feet per day (cfd) of LFG and continues to produce LFG for as many as 20 to 30 years after being landfilled. For more information on LFG modeling to estimate methane generation and recovery potential, see Chapter 2. Federal and/or state regulations require most large landfills to collect LFG and combust it, either by flaring or by using it in an LFG energy system. With a heating value of about 500 British thermal units (Btu) per standard cubic foot, LFG is a good source of useful energy. Many landfills collect and use LFG voluntarily to take advantage of this renewable energy resource while also reducing greenhouse gas emissions. For more information on regulations and permitting requirements, see Chapter 5. For more information about LFG and its effects on public health and the environment, see a U.S. EPA fact sheet of frequently asked questions.

1.2 LFG Collection and Treatment

LFG collection typically begins after a portion of the landfill (known as a "cell") is closed to additional waste placement. The most common method of LFG collection involves drilling vertical wells in the waste and connecting those wellheads to lateral piping that transports the gas to a collection header using a blower or vacuum induction system. Another type of LFG collection system uses horizontal piping laid in trenches in the waste. These systems are useful in deeper landfills and in areas of active filling. Some collection systems involve a combination of vertical wells and horizontal collectors. For more information about the types of LFG collection systems, see Chapter 3.

After collection, LFG can either be flared or used in an energy recovery system to combust the methane and other trace contaminants. Using LFG in an energy recovery system usually requires some treatment of the LFG to remove excess moisture, particulates, and other impurities. The type and extent of treatment depends on site-specific LFG characteristics and the type of energy recovery system employed. Boilers and most internal combustion engines generally require minimal treatment (e.g., dehumidification, particulate filtration, and compression). Some internal combustion engines and many gas turbine and microturbine applications also require siloxane removal using adsorption beds after the dehumidification step.[3] Figure 1-2 presents a diagram of an LFG energy project, including LFG collection, a fairly extensive treatment system, and an energy recovery system generating both electricity and heat. Most LFG energy projects produce either electricity or heat, although a growing number of combined heat and power (CHP) systems produce both.

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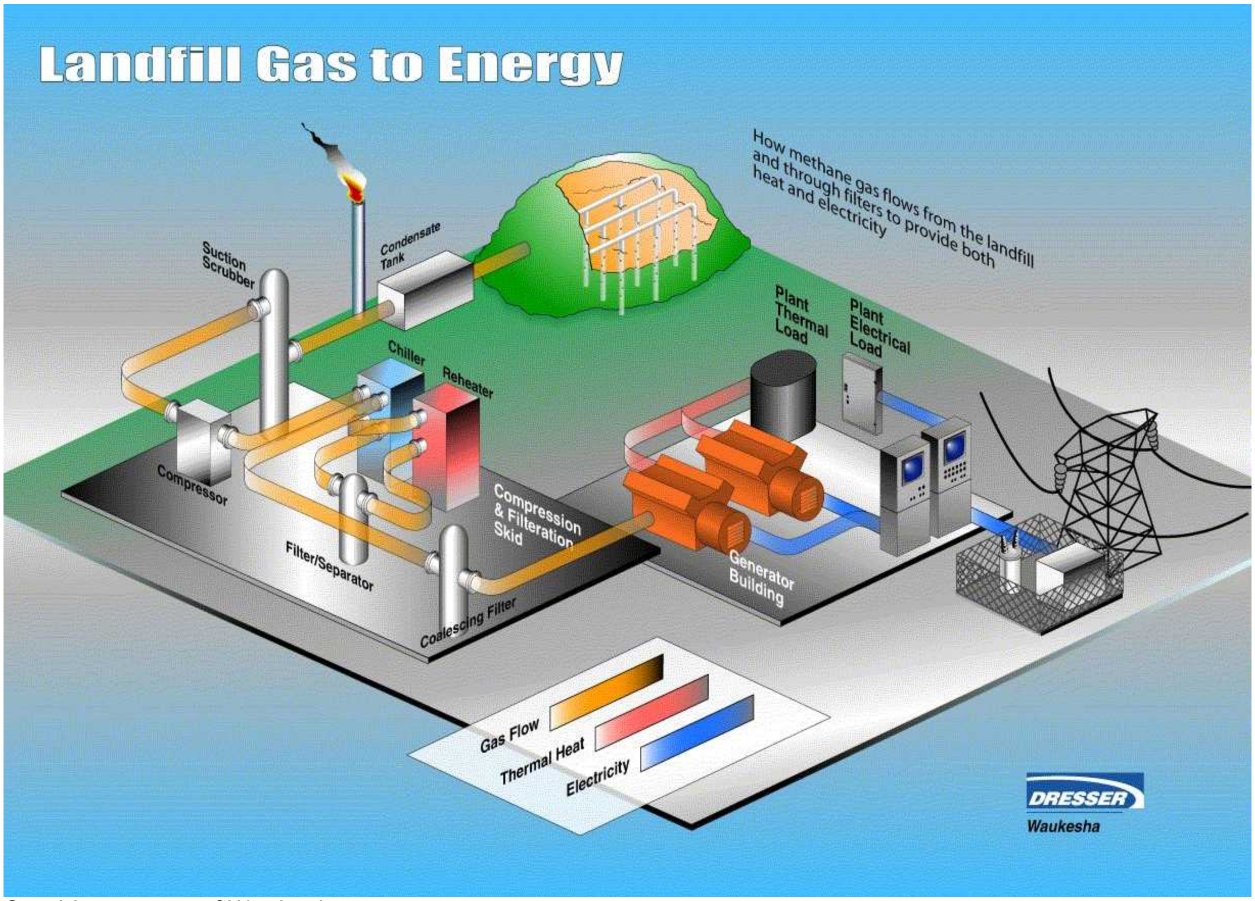
[2] Of the MSW generated in 2007, 33.4 percent was recovered through recycling or composting while 12.6 percent was combusted with energy recovery. Source: U.S. EPA. 2008. *Municipal Solid Waste in the United States — 2007 Facts and Figures.* EPA-530-R-08-010. Table ES-1, p. 2. http://www.epa.gov/epawaste/nonhaz/municipal/pubs/msw07-rpt.pdf

[3] Organo-silicon compounds, known as siloxanes, are found in household and commercial products that are discarded in landfills. Siloxanes find their way into LFG, although the amounts vary depending on the waste composition and age. When LFG is combusted, siloxanes are converted to silicon dioxide (the primary component of sand). Silicon dioxide is a white substance that collects on the inside of the internal combustion engine and gas turbine components, reducing the performance of the equipment and resulting in significantly higher maintenance costs. See Chapter 3 for further information.

Figure 1-2. LFG Collection, Treatment, and Energy Recovery

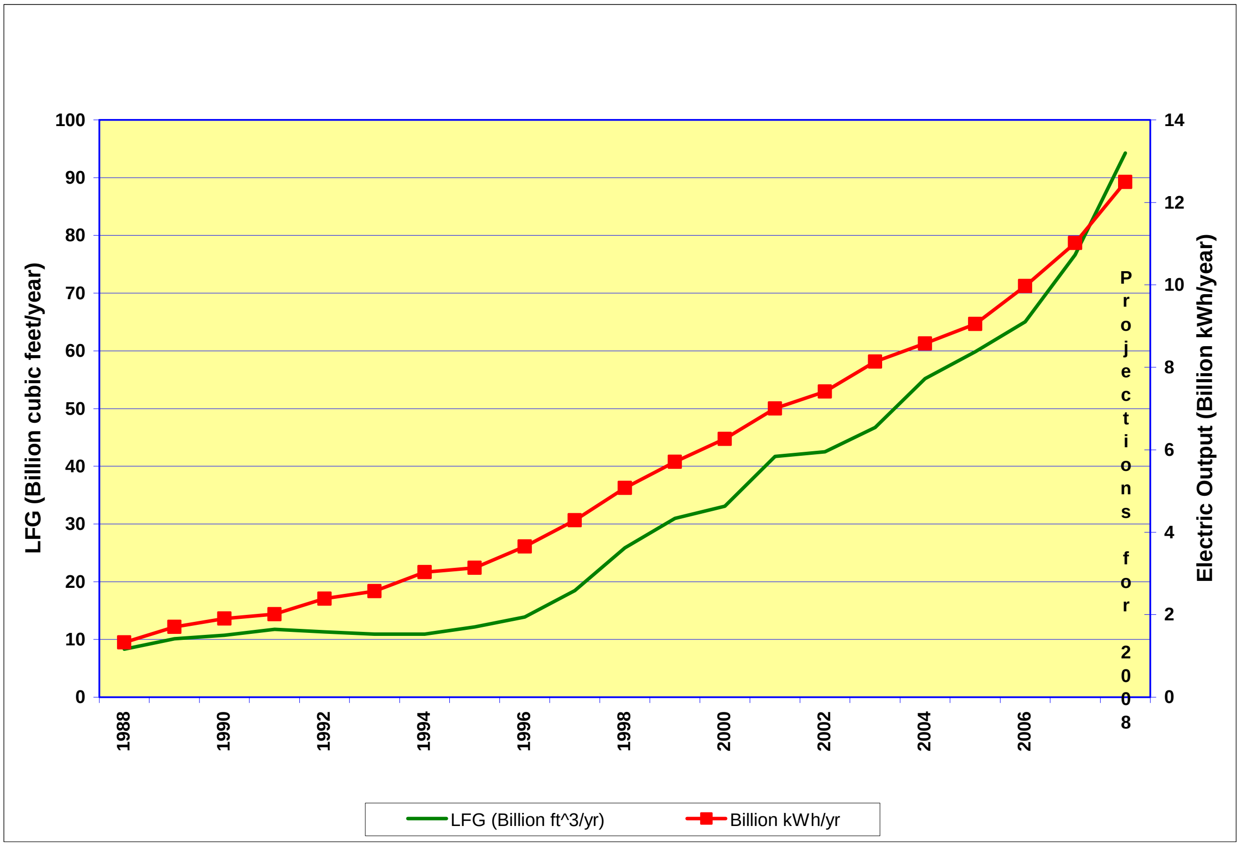


Graphic courtesy of Waukesha

1.3 LFG Energy Projects

Every million tons of MSW in a landfill is estimated to be able to produce approximately 432,000 cfd of LFG, which, through various technologies, could generate approximately 0.78 megawatts (MW) of power or provide 9 million Btu per hour (MMBtu/hr) of thermal energy. LFG energy projects first came on the scene in the mid- to late 1970s, but their implementation increased notably in the mid- to late 1990s as their track record for efficiency, dependability, and cost-savings was proven. The enactment of federal tax credits and regulatory requirements for LFG collection and control for larger landfills also helped spur this growth, as has increasing concern about climate change and demand for renewable energy. The growth in LFG energy project development from 1988 to 2008 has been steadily increasing, as depicted in Figure 1-3.

Figure 1-3. Growth in LFG Energy Project Output From 1988 to 2008: Electricity Generation and Direct Use



LMOP's Landfill and LFG Energy Project database, which tracks the development of U.S. LFG energy projects and landfills with project development potential, indicates that more than 400 LFG energy projects are currently operating in more than 40 states. Roughly two-thirds of these projects generate electricity, while one-third are direct-use projects in which the LFG is used for its thermal capacity. (Examples of direct-use projects include piping LFG to a nearby business or industry for use in a boiler, furnace, or kiln.) These 400+ projects are estimated to generate more than 11 billion kilowatt (kW)-hours of electricity and provide more than 75 billion cubic feet of LFG to direct end users annually. More information about these projects as well as landfills with potential to support LFG energy projects is available on the Energy Projects and Candidate Landfills page of LMOP's Web site.

There are numerous examples of LFG energy success stories. Some of these involve LMOP Partners coming together to overcome great odds to bring a project to fruition; others involve the use of innovative technologies and approaches, while still others were completed in record time. To read about some of these projects, see LMOP's LFG Energy Project Profiles page and the Media and Press section of the Web site.

Electricity Generation

The majority (more than 70 percent) of the LFG energy projects that generate electricity do so by combusting the LFG in internal combustion engines. The three most commonly used technologies — internal combustion engines, gas turbines, and microturbines — can accommodate a wide range of project sizes. Gas turbines are more likely to be used for large projects, usually for 5 MW or larger. Internal combustion engines are well-suited for 800 kW to 3 MW projects, but multiple units can be used together for projects larger than 3 MW. Microturbines, as their name suggests, are much smaller than turbines, with a single unit having between 30 and 250 kW in capacity, and thus are generally used for projects smaller than 1 MW. Small internal combustion engines are also available for projects in this size range. An LFG energy project may use multiple units to accommodate a landfill's specific gas flow over time. For example, a project might have three internal combustion engines, two gas turbines, or an array of 10 microturbines, depending on gas flow and energy needs. For more information about these technologies and others, see Chapter 3.

LFG energy CHP applications, also known as cogeneration projects, provide greater overall energy efficiency and are growing in number. In addition to producing electricity, these projects recover and beneficially use the heat from the unit combusting the LFG. LFG energy CHP projects can use internal combustion engine, gas turbine, or microturbine technologies.

Less common LFG electricity generation technologies include a few boiler/steam turbine applications, in which LFG is combusted in a large boiler to generate steam used by the turbine to create electricity. A few combined cycle applications have also been implemented. These combine a gas turbine that combusts the LFG with a steam turbine that uses steam generated from the gas turbine's exhaust to create electricity. Boiler/steam turbine and combined cycle applications tend to be larger in scale than the majority of LFG electricity projects that use internal combustion engines.

Direct Use

Direct use of LFG is often a cost-effective option when a facility that could use LFG as a fuel in its combustion or heating equipment is located within approximately 5 miles of a landfill; however distances of 10 miles or more can also be economically feasible in some situations. Some manufacturing plants have chosen to locate near a landfill for the express purpose of using LFG as a renewable fuel that is cost-effective when compared to natural gas. Figure 1-4 reflects the diversity of companies using LFG in their processes.

Figure 1-4. Look Who's Using LFG

The number and diversity of direct-use LFG applications is continuing to grow. Project types include:

- *Boilers*, which are the most common type of direct use and can often be easily converted to use LFG alone or in combination with fossil fuels.
- *Direct thermal applications,* which include kilns (e.g., cement, pottery, brick), sludge dryers, infrared heaters, paint shop oven burners, tunnel furnaces, process heaters, and blacksmithing forges, to name a few.
- *Leachate evaporation*, in which a combustion device that uses LFG is used to evaporate leachate (the liquid that percolates through a landfill). Leachate evaporation can reduce the cost of treating and disposing of leachate.

The creation of pipeline-quality, or high Btu, gas from LFG is becoming more prevalent. In this process, LFG is cleaned and purified until it is at the quality that can be directly injected into a natural gas pipeline. Also growing in popularity are projects in which LFG provides heat for processes that create alternative fuels (e.g., biodiesel or ethanol). In some cases, LFG is directly used as feedstock for an alternative fuel (e.g., compressed natural gas [CNG], liquefied natural gas [LNG], or methanol). Only a handful of these projects are currently operational, but several more are in the construction or planning stages. LFG has also found a home in a few greenhouse operations. For more information about these technologies and others, see Chapter 3.

1.4 Environmental and Economic Benefits of LFG Energy Recovery

Developing LFG energy projects is an effective way to reduce greenhouse gas emissions, improve local air quality, and control odors. These projects also provide numerous other environmental and economic benefits to the community, the landfill, and the energy end user.

> The more than 400 currently operational LFG energy projects provide greenhouse gas reduction benefits that are equivalent to any one of the following:
>
> - Carbon sequestered annually by nearly 18 million acres of pine or fir forests.
> - Carbon dioxide emissions from 182 million barrels of oil consumed.
> - Annual greenhouse gas emissions from more than 14 million passenger vehicles.
>
> These projects also provide enough energy to power more than 870,000 homes and heat nearly 534,000 homes annually.

Environmental Benefits

MSW landfills are the second-largest human-caused source of methane emissions in the United States.[4] Given that all landfills generate methane, there is great opportunity to use the gas from as many landfills as possible for energy generation rather than letting it go into the atmosphere or flaring it without energy recovery. Methane is a very potent heat-trapping gas (more than 20 times stronger than carbon dioxide) so is a key contributor to global climate change. Methane also has a short atmospheric life (i.e., 10 to 14 years). Because methane is both potent and short-lived, reducing methane emissions from MSW landfills is one of the best ways to achieve a near-term beneficial impact in lessening the human impact on global climate change.

Direct Greenhouse Gas Reductions. During its operational lifetime, an LFG energy project will capture an estimated 60 to 90 percent of the methane created by a landfill, depending on system design and effectiveness. The captured methane is converted to water and carbon dioxide when the gas is burned to produce electricity or heat.[5]

Indirect Greenhouse Gas Reductions. Producing energy from LFG displaces the use of non-renewable resources (such as coal, oil, or natural gas) that would be needed to produce the same amount of energy. This avoids greenhouse gas emissions from fossil fuel combustion by an end user facility or power plant.[6]

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[4] U.S. EPA. 2008. Chapter 8: Waste. In *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2006.* EPA-430-R-08-005. http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

[5] Carbon dioxide emissions from MSW landfills are not considered to contribute to global climate change because the carbon was contained in recently living biomass (i.e., is biogenic) and the same carbon dioxide would be emitted as a result of the natural decomposition of the organic waste materials if they were not in the landfill. This is consistent with international greenhouse gas protocols such as 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5: Waste, http://www.ipcc-nggip.iges.or.jp/public/2006gl/.

[6] The carbon in fossil fuels was not contained in recently living biomass; rather, the carbon was stored when ancient biomass was converted to coal, oil, or natural gas and would therefore not have been emitted had the fossil fuel not been extracted and burned. Carbon dioxide emissions from fossil fuel combustion are a major contributor to climate change.

Direct and Indirect Reduction of Other Air Pollutants. The capture and use of LFG at a landfill can benefit local air quality. Non-methane organic compounds that are present at low concentrations in LFG are destroyed during combustion, reducing possible health risks from these compounds. For electricity projects, the avoidance of fossil fuel combustion at utility power plants means that fewer pollutants such as sulfur dioxide (which is a major contributor to acid rain), particulate matter (a respiratory health concern), nitrogen oxides (which can contribute to local ozone and smog formation), and trace hazardous air pollutants are released into the air by utilities.

Equipment that burns LFG to generate electricity does generate some emissions, including nitrogen oxides. These emission levels depend on the type of equipment used. However, the overall environmental improvement achieved from LFG energy projects is significant because of the direct methane reductions, indirect carbon dioxide reductions, and direct and indirect reduction in other air pollutant emissions. There is also an energy benefit in avoiding the use of limited non-renewable resources such as coal and oil.

Other Environmental Benefits. Collecting and combusting LFG improves the quality of the surrounding community by reducing landfill odors, which are usually caused by sulfates in the gas. Gas collection can also improve safety by reducing migration of the gas to structures where the gas could accrue and cause explosion hazards.

Additional information about LFG environmental, safety, and public health concerns is found in an LMOP Frequently Asked Questions document. The LFG Energy Benefits Calculator can be used to estimate direct methane reductions, indirect carbon dioxide reductions, and equivalent environmental benefits for your LFG electricity or direct-use project.

Economic Benefits

For the Landfill Owner. Landfill owners can receive revenue from the sale of LFG to a direct end user or pipeline, or from the sale of electricity generated from LFG to the local power grid. (For more information about options when setting up a contract, see Chapter 5.) Depending on who owns the rights to the LFG and other factors, a landfill owner may also be eligible for revenue from renewable energy certificates (RECs), tax credits and incentives, renewable energy bonds, and greenhouse gas emissions trading. For more information about these items, see Chapter 4 and LMOP's online funding guide. All these potential revenue sources can help offset gas collection system and energy project costs for the landfill owner. For example, if the landfill owner is required to install a gas collection and control system, going the extra step of using the LFG as an energy resource — rather than installing a flare to combust the LFG without energy recovery — can help pay down the capital cost required for the control system installation.

> A public/private partnership to develop an electricity-generating LFG energy project at Catawba County's Blackburn Landfill in Newton, North Carolina, will generate revenues of $7.1 million dollars for the County over the project's lifetime. Among other things, this will allow the County to keep tipping fees at their current level for 10 years. The LFG electricity provides Duke Energy (the electricity purchaser) with a renewable energy resource, and the greenhouse gas emission reductions are equivalent to the annual greenhouse gas emissions from 2,700 passenger vehicles.

For the End User. Businesses and other organizations, such as universities and government facilities, can save significantly on energy costs by choosing LFG as a direct fuel source in place of potentially more expensive fossil fuels whose price is subject to market volatility. Some end users can save millions of dollars over the duration of their LFG energy projects. Some companies report achieving indirect economic benefits through media exposure that portrays them as leaders in the use of renewable energy. For end users' perspectives about using LFG, see quotes from industry leaders.

> General Motors converted one of three powerhouse boilers at an Indiana plant to use LFG in addition to natural gas. The boiler produces steam to heat assembly plant and process equipment and to drive turbines to produce chilled water and pump water. The facility saves about $500,000 annually in energy costs; the greenhouse gas emission reductions equate to the carbon dioxide emissions from nearly 51,000 barrels of oil consumed.

> Springfield Gas and International Truck and Engine Corporation reached out to the community through public meetings, fact sheets, and individual visits to gain support for the permitting and development of a direct-use project in Springfield, Ohio. Five years after their efforts began, International began using LFG in place of natural gas in paint ovens, boilers, and other equipment, for an expected savings of $100,000 per year in fuel costs.

> The first LFG energy project implemented by BMW Manufacturing in South Carolina involved four gas turbines with heat recovery, which met 25 percent of the plant's electric needs and nearly all of its thermal needs. A few years later, BMW converted equipment in the paint shop to use even more LFG, so that this renewable resource now satisfies 63 percent of the facility's energy consumption. BMW estimates its savings at $1 million per year.

For the Community. LFG energy project development can greatly benefit the local economy. Temporary jobs are created for the construction phase, while design and operation of the collection and energy recovery systems create long-term jobs. LFG energy projects involve engineers, construction firms, equipment vendors, and utilities or end users of the power produced. Some materials for the overall project may be purchased locally, and often local firms are used for construction, well drilling, pipeline installation, and other services. In addition, hotel rooms and meals for the workers provide a boost to the local economy. Some of the money paid to workers and local businesses by the LFG energy project gets spent within the local economy on goods and services, resulting in indirect economic benefits. In some cases, LFG energy projects have led new businesses (e.g., brick and ceramics plants), greenhouses, or craft studios, to locate near the landfill to use LFG. Such new businesses add depth to the local economy.

> Construction of a direct-use project using LFG from the Lanchester Landfill in Narvon, Pennsylvania, created over 100 temporary construction jobs, involved the purchase of local materials, and infused millions of dollars into the local economy.
>
> A direct-use project in Virginia requiring a 23-mile long pipeline to transport LFG to Honeywell provided jobs and revenue to the local town. For example, building the pipeline resulted in 22,000 hotel stays in Hopewell, Virginia.

The EnergyXchange Renewable Energy Center, located at the foot of the Black Mountains in western North Carolina, has brought national attention to the region and its artisans through a small-scale but far-reaching LFG energy project. Glass blowers, potters, and greenhouse students have benefitted from the local supply of LFG, through saved energy costs, education and hands-on experience, and recognition of their crafts. The artisans' savings have already exceeded $1 million.

The ecology club at Pattonville High School in Maryland Heights, Missouri, suggested to the school board that they consider using excess LFG from the nearby Fred Weber Landfill in the school's boilers. Feasibility analyses determined that the savings were worthwhile and a partnership was born. With a loan, a grant, and capital from Fred Weber, the direct-use project was brought to fruition, and the school saves about $27,000 per year.

Jobs and Revenue Creation

- A typical 3 MW LFG electricity project is estimated to have the following benefits (direct, indirect, and induced) during the construction year:
  - Increase the output of the national economy by ~$14 million ($3 million of which is a local benefit and mostly employee earnings).
  - Employ nearly 70 people nationally (expressed in full-time equivalents [FTE] per year).
- A typical 1,040 standard cubic foot per minute (scfm) LFG direct-use project is estimated to have the following benefits (direct, indirect, and induced) during the construction year:

  5-mile pipeline:
  - Increase the output of the national economy by ~$6 million ($2 million of which is a local benefit and mostly employee earnings).
  - Employ 43 people nationally (expressed in FTE per year).

  10-mile pipeline:
  - Increase the output of the national economy by ~$12 million ($4 million of which is a local benefit and mostly employee earnings).
  - Employ 80 people nationally (expressed in FTE per year).

1.5 Steps to LFG Energy Project Development

The following section provides a basic overview of the steps involved in developing an LFG energy project. Landfill owners can use several mechanisms to implement projects in their communities and promote the use of LFG as a renewable energy resource. There are nine broad steps when implementing an LFG energy project:

1. *Estimate LFG Recovery Potential and Perform Initial Assessment.* In this first step, the landfill owner or other party would determine if the landfill site is likely to produce enough methane to support an energy recovery project. Screening criteria include whether the landfill contains at least 1 million tons of MSW, has a depth of 50 feet or more, and is open or recently closed. In addition, the site should receive at least 25 inches of precipitation annually. Landfills that meet these criteria are likely to generate enough gas to support an LFG energy project. It is important to note that these are only ideal conditions, and many successful LFG energy projects have been developed at smaller, older, and/or more arid landfills. Once it is

determined that the energy recovery option is viable, the next step is to estimate gas flow. EPA's Landfill Gas Emissions Model (LandGEM) can provide a more detailed analysis of LFG generation potential. See Chapter 2.

2. *Evaluate Project Economics.* The next step in project development is to perform a detailed economic assessment of converting LFG into a marketable energy product such as electricity, steam, boiler fuel, vehicle fuel, or pipeline quality gas. A variety of technologies can be used to maximize the value of LFG when producing these energy forms. The best configuration for a particular landfill will depend on a number of factors including the existence of an available energy market, project costs, potential revenue sources, and other technical considerations. LMOP's LFGcost-Web tool, available to LMOP Partners, can help with preliminary economic evaluation. See Chapters 3 and 4.

3. *Establish Project Structure.* Options for how to develop and manage an LFG energy project include:

   - The landfill owner can develop/manage the project internally.
   - The landfill owner can team with a project developer. The developer finances, constructs, owns, and operates the project.
   - The landfill owner can team with partners (e.g., equipment supplier, energy end user).

   LMOP can assist with project partnering by identifying potential matches and distributing requests for proposals (RFPs). See Chapter 6 for more information on project structures and evaluating project partners.

4. *Draft Development Contract.* If the project structure involves a partnership, the terms of the partnership should be formalized in a development contract, which includes determining which partner will own the gas rights and the rights to potential emissions reductions. The contract will also determine partner responsibilities including design, installation, operation, and maintenance. Contracting with a developer is a complex issue and each contract will be different depending on the specific nature of the project and the objective and limitations of the participants. See Chapters 5 and 6.

5. *Assess Financing Options.* Financing an LFG energy project is one of the most important and challenging tasks facing a landfill owner or project developer. A number of potential financing avenues are available, including finding equity investors, obtaining loans form investment companies or banks, and issuing municipal bonds. Five general categories of financing methods may be available to LFG energy projects: private equity financing, project financing, municipal bond funding, direct municipal financing, and lease financing. For a full description of these financing mechanisms, see Chapter 4. In addition to financing options, there are a variety of financial incentives available at the federal and state level. Local governments are eligible for some of these incentives, which are described in detail in LMOP's funding guide: Funding Landfill Gas Energy Projects: State, Federal, and Foundation Resources.

6. *Negotiate Energy Sales Contract.* This contract exists between the LFG energy project owner and the end user and specifies the amount of gas or power to be delivered and at what price.

An energy sales contract will determine the success or failure of the project since it secures the project's source of revenue. Therefore, successfully obtaining this contract is a crucial milestone in the project development process. Because the contract negotiation is often a complex process, owners and developers should consult an expert for further information and guidance. Negotiating an energy sales contract involves the following steps: preparing a draft offer contract, determining utility or end user need for power or gas demand, developing project design and pricing, preparing and presenting a bid package, reviewing contract terms and conditions, and signing the contract. See Chapter 5.

7. *Secure Permits and Approvals.* Obtaining required environmental, siting, and other permits is an essential step in the development process. Permit conditions often affect project design and neither construction nor operation can begin until the appropriate permits are in place. The process of permitting an LFG energy project may take anywhere from six to 18 months (or longer) to complete, depending on the project's location and recovery technology. LFG energy projects must comply with federal regulations related to both the control of LFG emissions and the control of air emissions from the energy conversion equipment. Regulations promulgated under two separate federal acts, the Resource Conservation and Recovery Act (RCRA) and the Clean Air Act, address emissions from MSW landfills. During this phase of the project, the landfill owner should contact and meet with regulatory authorities to determine requirements and educate the local officials, landfill neighbors, and nonprofit and other public interest and community groups about the benefits of the project. Chapter 5 summarizes federal regulations and permitting requirements, and LMOP's state primers provide useful information regarding state-specific regulations and permits.

8. *Contract for Engineering, Procurement, and Construction (EPC) and Operation and Maintenance (O&M) Services.* Constructing and operating LFG energy projects is a complex process, so it may be best managed by a firm with proven experience gained over the course of implementing similar projects. Landfill owners that choose to contract with EPC and O&M firms should take the following steps: soliciting bids from EPC/O&M contractors, selecting the EPC/O&M contractor, and negotiating the contract. The selected EPC/O&M contractor conducts the engineering design, site preparation and plant construction, and startup testing. See Chapter 6.

9. *Install Project and Start Up.* The final phase of implementation is the start of commercial operations. This phase is often commemorated with ribbon-cutting ceremonies, public tours, and press releases. LMOP offers an online Toolkit containing templates and tips for these events.

1.6 LMOP Resources and Services

LMOP is a voluntary assistance and partnership program created by EPA in 1994 to reduce methane emissions by encouraging the recovery and use of LFG as a renewable, green energy resource. LMOP's Web site has become one of the main modes of providing LMOP Partners, others in the industry, and the public with basic information and keeping them abreast of the latest LFG energy–

related advances and opportunities. LMOP has developed many publications and tools to assist those wishing to develop LFG energy projects or promote LFG to various audiences. LMOP also provides customized, direct assistance to individual Partners to address their needs.

Joining LMOP as a Partner or Endorser

Organizations partner with LMOP voluntarily to gain a greater understanding of LFG efforts and to build connections with other interested parties. EPA established five types of Partner programs (Industry, Energy, Community, State, and Endorser) to assist different sectors of the LFG field. LMOP works with landfill owners/operators, industry organizations, energy providers and marketers, state agencies, communities, end users, and other stakeholders to help them overcome barriers to LFG energy development. LMOP does so by providing access to technical assistance, conducting outreach, and fostering relationships between Partners. Basic information about current Partners, including contacts and areas of expertise, is posted on LMOP's Web site monthly for other Partners and the general public to see and potentially contact them (e.g., for their services or about their landfill). To join LMOP, organizations read, sign, and submit a memorandum of understanding (MOU), electronic versions of which are available on the Join the Program page of LMOP's Web site.

Landfill and LFG Energy Project Database

LMOP's Landfill and LFG Energy Project database is the most comprehensive data repository for LFG energy projects and landfills with potential for energy recovery in the country. It is updated continually with information from LMOP Partners and other organizations in the industry. LMOP posts Excel files on the Web site for anyone to view and download. On the Web page, users can view data for a specific project type of interest, for landfills that are good candidates for energy project development, or for all projects and landfills in a single state. In addition to posted data, LMOP maintains a master database with some additional fields and can provide information from the database to address specific questions.

Direct Assistance for Developing LFG Energy Projects

LMOP offers direct assistance throughout the development of a project, from providing basic information about LFG energy in the early stages of project consideration, to preliminary analyses of project feasibility, to providing media support when the project reaches the construction or commercial operation phase. Services LMOP offers include:

- Matching landfills and end users. When assisting a landfill owner/operator or project developer, LMOP can help identify potential end users for the project. When assisting a potential end user, LMOP can search for nearby landfills that are good candidates for project development.

- Making preliminary estimates of recoverable methane using LFG models such as LandGEM and site-specific information on landfill waste acceptance.

- Assisting with preliminary technical and economic feasibility assessments for LFG energy project options. (Before entering into partnerships and agreements to develop an LFG energy project, interested parties will of course need to have a more detailed site-specific estimate performed by a professional with LFG energy experience.)

- Helping to locate project partners through networking opportunities and by distributing RFPs through listserv messages.
- Answering technical questions and providing information to help overcome barriers to LFG energy projects, including technical and permitting issues. LMOP can also attend meetings with stakeholders to address questions about LFG energy and foster positive interactions among landfill owners, developers, end users, regulatory agencies, community groups, and other stakeholders.
- Providing positive publicity for LFG energy projects by developing recognition materials for project ribbon-cuttings, publicizing a project through LMOP's newsletter, and recognizing outstanding Partners and projects via LMOP's annual awards.

Online Tools to Assist With Project Development

The LMOP Funding Guide, updated quarterly, lists many innovative funding programs and strategies that can help developers and landfill owners overcome financial barriers. These programs and strategies include loans, grants, low-interest loans, production incentives, tax credits, and exemptions from property, sales, and use taxes. The funding guide provides a narrative description of each resource listed, contact information, and links to each resource's Web page where application materials can be downloaded, if available.

LMOP's Interactive Conversion Tool allows a user to easily perform unit conversions, such as standard cubic feet per minute (scfm) to million standard cubic feet per day (mmscfd) or short tons of methane to metric tons of carbon dioxide equivalents. It can also be used to provide a very preliminary estimate of the LFG energy potential from a landfill, for example, by providing results in scfm of LFG or MW capacity based on an input of tons of waste-in-place.

LFG models to estimate a landfill's potential methane generation and recovery over time can be accessed from the LMOP Web site. These include EPA's LandGEM software to estimate methane for U.S. landfills, and LMOP's international LFG models that have been customized for other countries or regions in the Software section of the Documents, Tools, and Resources page.

LFGcost-Web, a model that can be used to provide a preliminary assessment of the economic feasibility of a variety of LFG energy project options for an individual landfill, is available to LMOP Partners online. Users should have a good understanding of factors that influence LFG energy project costs and revenues before using this software. The online version includes several simplifying assumptions. If these assumptions are not representative of your landfill, LMOP can assist by providing an analysis that is more tailored to your landfill and potential project.

The LFG Energy Benefits Calculator enables users to estimate an LFG energy project's direct methane reductions, avoided carbon dioxide emissions (when LFG is used instead of a fossil fuel to generate electricity or fuel a process), and total greenhouse gas reductions. It also provides equivalent environmental and energy benefits for the current year. The calculator can be a useful tool when writing a press release or other media-based announcement regarding an LFG energy project.

LMOP's online Toolkit is designed to help LMOP Partners and others communicate LFG energy benefits and develop outreach materials. The toolkit features sample outreach tools (e.g., communication tips, talking points, checklists for ribbon-cutting and groundbreaking ceremonies, and press release templates) to help project partners share the good news about LFG energy projects with their community, employees, shareholders, customers, the media, and other stakeholders.

Documents

LMOP's Documents, Tools, and Resources page provides access to technical documents, informational brochures, state LFG primers, fact sheets, case studies, press releases, and media reports. Examples include:

- A brochure specifically developed for potential corporate end users of LFG.
- A fact sheet providing information on adapting boilers to utilize LFG.
- Several state primers that provide information on landfills, state regulations, policies, procedures, and assistance available for LFG energy project development in individual states.

LMOP's Web site also provides a Frequently Asked Questions (FAQ) page for questions about the program itself, about LFG energy projects in general, and about how LFG affects public health, safety, and the environment.

Newsletters, E-mails, and Conferences

The *Gasette*, LMOP's online newsletter, includes articles about new LFG energy projects, industry trends, conferences, new regulations and incentives that affect or encourage LFG energy projects, and LFG energy advancement in the international community.

LMOP also sends timely LFG energy–related listserv messages to Partners and other interested parties to notify them of RFPs, upcoming events of interest, and funding opportunities. To receive these messages, submit the contact form from the LMOP Web site or contact LMOP directly.

LMOP's annual conference provides opportunities to network with other organizations in the LFG energy industry and learn about exciting projects, technologies, and innovative ideas presented during topical sessions and from exhibitors. Visit the LMOP Web site for information on future conferences and presentations from previous conferences. The conference includes a Project Expo that showcases several landfills with LFG energy project development potential to developers and other interested parties.

2. Landfill Gas Modeling

Chapter Overview

Landfill gas (LFG) modeling is the practice of forecasting gas generation and recovery based on past and future waste disposal histories and estimates of collection system efficiency. LFG modeling is an important step in the project development process, because it provides an estimate of the amount of recoverable methane that will be available over time to fuel an LFG energy project.

LFG modeling is performed for regulatory and non-regulatory purposes. *Regulatory applications* of LFG models for U.S. landfills are conducted to estimate emissions of LFG and its constituents, including non-methane organic compounds (NMOCs). These emissions estimates establish the requirements for gas collection and control system installation and operation. The modeler inputs landfill-specific waste disposal estimates but uses values for input variables (e.g., the methane generation rate) as determined by applicable regulations.

Non-regulatory applications of LFG models typically include any of the following:

- Evaluating LFG energy project feasibility
- Determining gas collection and control system design requirements
- Performing due diligence evaluations of potential or actual project performance

This chapter covers non-regulatory LFG modeling applications only. EPA does not intend for the material presented in this handbook to supersede or replace required procedures for preparing LFG models for regulatory purposes. Federal regulations such as the New Source Performance Standards (NSPS) require modeling to determine rule applicability and compliance. For regulatory applications, the modeler must use the specific procedures, default vales, and test methods prescribed in the rule. Refer to the appropriate regulations (e.g., the NSPS [40 CFR part 60 subpart WWW] and related documentation) for details.

2.1 Introduction to LandGEM

The most widely used LFG model is EPA's Landfill Gas Emissions Model (LandGEM). LandGEM is the industry standard model for regulatory and non-regulatory applications in the United States. The latest version of LandGEM (v. 3.02) was released in May 2005. This section provides an introduction to LandGEM and the first order decay equation and variables employed by the model.

The First-Order Decay Equation

LandGEM is a first order decay model. First order decay models assume that landfill methane generation is at its peak shortly after initial waste placement (after a short time lag during which anaerobic conditions are established in the landfill). They also assume that landfill methane generation then decreases exponentially (i.e., first order decay) as the organic material in the waste decreases as it is degraded by bacteria in the landfill.

LandGEM assumes that landfill methane generation can be projected using the following first order exponential equation:

$$Q_{CH4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k\, L_o\, (M_i/10)\, (e^{-kt_{ij}})$$

Where:

Q_{CH4} = estimated methane generation flow rate (in cubic meters [m^3] per year or average cubic feet per minute [cfm])

i = 1-year time increment

n = (year of the calculation) – (initial year of waste acceptance)

j = 0.1-year time increment

k = methane generation rate (1/year)

L_o = potential methane generation capacity (m^3 per megagram [Mg] or cubic feet per ton)

M_i = mass of solid waste disposed in the i^{th} year (Mg or ton)

t_{ij} = age of the j^{th} section of waste mass disposed in the i^{th} year (decimal years)

LandGEM calculates methane generation using the first order decay equation shown above, and it calculates LFG generation by dividing methane generation by the estimated percent methane. The default methane content is 50 percent, which is both the industry standard value and LMOP's recommended default value.

Model Inputs

Of the several variables in the first order decay equation used by LandGEM, only three (M_i, L_0, and k) require user inputs. The user assigns these variables in a "USER INPUTS" worksheet in LandGEM. The following sections describe the three variables and their effects on estimated LFG generation.

Annual Waste Disposal Rates (M_i). Estimated waste disposal rates are the primary determinant of LFG generation in any first order decay-based model, including LandGEM. LandGEM does not adjust annual waste disposal estimates to account for waste composition. Adjustments to account for waste composition are typically handled by adjustments to the L_0 value.

Potential Methane Generation Capacity (L_0). The potential methane generation capacity, or L_0, describes the total amount of methane gas potentially produced by a metric ton of waste as it decays. The values of the theoretical and obtainable L_0 range from 6.2 to 270 cubic meters per metric ton or megagram (m^3/Mg) of waste.[1] Except in dry climates where lack of moisture can limit methane generation, the value for the L_0 depends almost entirely on the type of waste present in the landfill. The higher the organic content of the waste, the higher the value of L_0. Note that the dry

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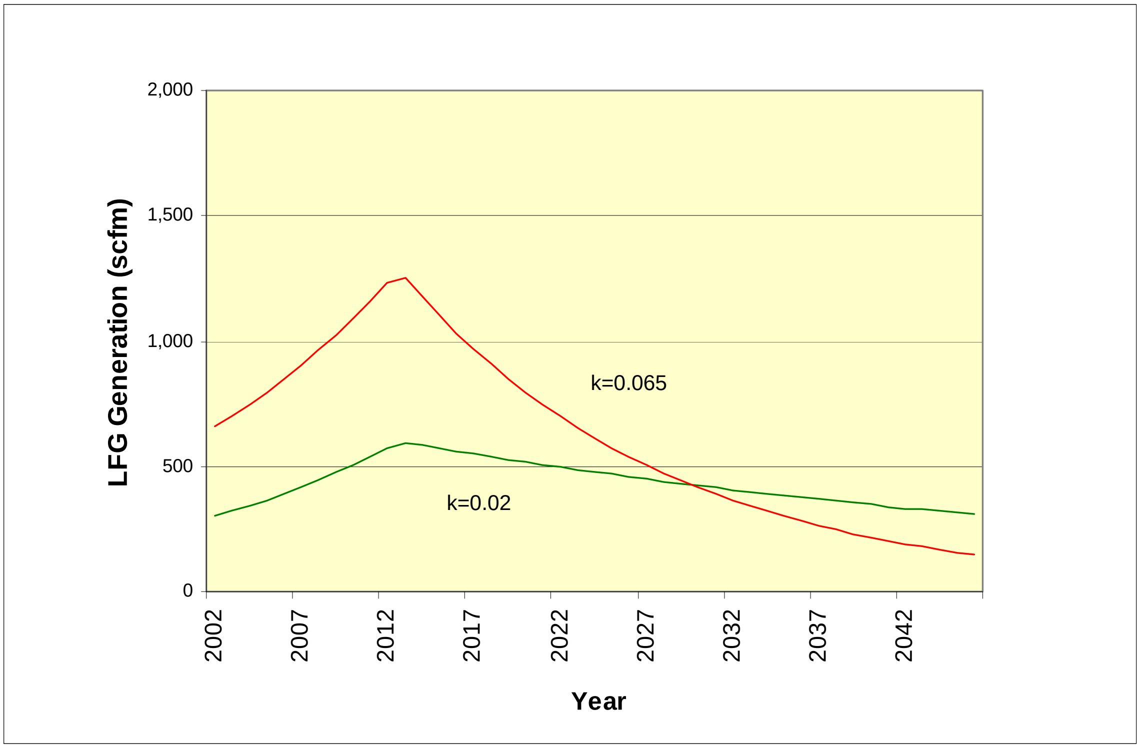
[1] U.S. EPA. 1991. *Air Emissions From Municipal Solid Waste Landfills — Background Information for Proposed Standards and Guidelines.* EPA-450-3-90-011a. p. 3-22.

organic content of the waste determines the L_0 value, not the wet weight measured and recorded at landfill scalehouses, since water does not generate LFG.

Methane Generation Rate Constant (k). The methane generation rate constant, k, describes the rate at which waste placed in a landfill decays and produces LFG. The k value is expressed in units of $year^{-1}$. At higher values of k, the methane generation at a landfill increases more rapidly (as long as the landfill is still receiving waste), and then declines more quickly after the landfill closes. The value of k is a function of (1) waste moisture content, (2) availability of nutrients for methane-generating bacteria, (3) pH, and (4) temperature. Figure 2-1 shows an example gas curve for a landfill with approximately 2 million tons waste-in-place expected at closure. The potential gas generation was modeled in two scenarios, using identical landfill parameters except that k was varied between a value for arid conditions (0.02 yr^{-1}) and a value for wet conditions (0.065 yr^{-1}). The graph demonstrates the significant difference in gas generation that can occur based on moisture conditions at the site.

Figure 2-1. LFG Generation Variance by k Value



Moisture conditions within a landfill strongly influence k values and reflect the climate at the site as well as the contents of disposed waste and landfill design and operating practices. Waste decay rates and k values are very low at desert sites, tend to be higher at sites in rainier climates, and reach maximum levels under moisture enhanced “bioreactor” conditions. Annual precipitation is often used as a surrogate for waste moisture due to the lack of information on moisture conditions within a landfill. Air temperature can also affect k values, but to a lesser extent. Internal landfill temperatures are relatively independent of outside temperatures and typically remain in the range of approximately 30 to 60°C (85 to 140°F) except at shallow, unmanaged landfills in very cold climates (e.g., landfills located in areas above 50 degrees latitude). For such landfills, waste decay rates and k values tend to be lower.

The k value can also be expressed as a half-life, $t_{1/2}$. The half-life is the time required for half of the remaining methane generation potential to be produced (i.e., half of the deposited waste to decay and produce LFG).

Refer to the LandGEM User's Manual for additional details on model use.

Model Outputs

LFG Generation. After the model inputs are selected, the user can turn to the "RESULTS" worksheet in LandGEM to find model outputs. The outputs include annual waste inputs, waste-in-place, and generation of total LFG, methane, carbon dioxide, and NMOCs. LFG and methane generation estimates are the output parameters that are used for non-regulatory LFG predictions. Once the LFG and methane generation is estimated, the collection efficiency must be estimated to determine the expected amount of LFG available for an LFG energy project

2.2 Estimating LFG Gas Recovery

Estimating Collection Efficiency

Collection efficiency is a measure of the gas collection system's ability to capture generated LFG. The LFG generation predicted by the model can be multiplied by the percent collection efficiency to estimate the volume of LFG that can be recovered for flaring or use in an LFG energy project. Although rates of LFG capture can be measured, rates of generation in a landfill cannot be measured; therefore, considerable uncertainty exists regarding actual collection efficiencies achieved at landfills.

To help address the uncertainty surrounding collection efficiencies, EPA has published estimates of reasonable collection efficiencies for U.S. landfills that meet U.S. design standards[2] and that have "comprehensive" gas collection systems. EPA defines a "comprehensive" LFG collection system as a system of vertical wells and/or horizontal collectors providing 100 percent collection system coverage of all areas with waste within one year after the waste is deposited. According to EPA, collection efficiencies at such landfills typically range from 60 to 85 percent, with an average of 75 percent most commonly assumed.[3] Most landfills, particularly those that are still receiving wastes, will have less than 100 percent collection system coverage. In such cases, LFG modelers commonly use a "coverage factor" to adjust the estimated collection efficiency. The coverage factor adjustment is applied by multiplying the collection efficiency by the estimated percentage of the fill areas with

[2] Landfills that meet or exceed the requirements in the 40 CFR Parts 257 and 258 RCRA Subtitle D Criteria.

[3] U.S. EPA. 1998. Volume 1, Chapter 2, Section 2.4: Municipal Solid Waste Landfills. In *AP42 Compilation of Air Pollutant Emission Factors.* Fifth Edition. p. 2.4-6. http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf.

wells. This adjustment also should be applied to areas where wells are not fully functioning or are watered in.

Collection efficiency estimates for sites with an operating gas collection and control system are typically based on information regarding current or recent conditions. Historical and future collection efficiency estimates can be made based on current conditions or other information regarding historical and planned collection system installations/expansions. Collection efficiency usually increases after site closure when disposal operations stop interfering with LFG system operations and a final cover is installed. Sites without collection systems installed are typically assumed to be planning to install a comprehensive system, unless there is site-specific information to suggest a different value.

Estimating LFG Recovery

The final step in the modeling process is to calculate LFG recovery based on LandGEM projections of LFG generation and the modeler's estimated collection efficiency. This step is done outside LandGEM and can be accomplished by setting up a spreadsheet that provides the LFG generation estimates, the collection efficiency estimates, and LFG recovery estimates (product of generation and percent efficiency). Table 2-1 shows a recommended format for displaying results and the waste disposal estimates on which they are based.

Table 2-1. LFG Generation and Recovery Projections

Year	Disposal Rate	Waste-in-Place	LFG Generation		Collection Efficiency	LFG Recovery	
	(tons/year)	(tons)	(scfm)	(m^3/hr)	(%)	(scfm)	(m^3/hr)
Year 1							
Year 2							
Year 3							
Year X (final year modeled)							

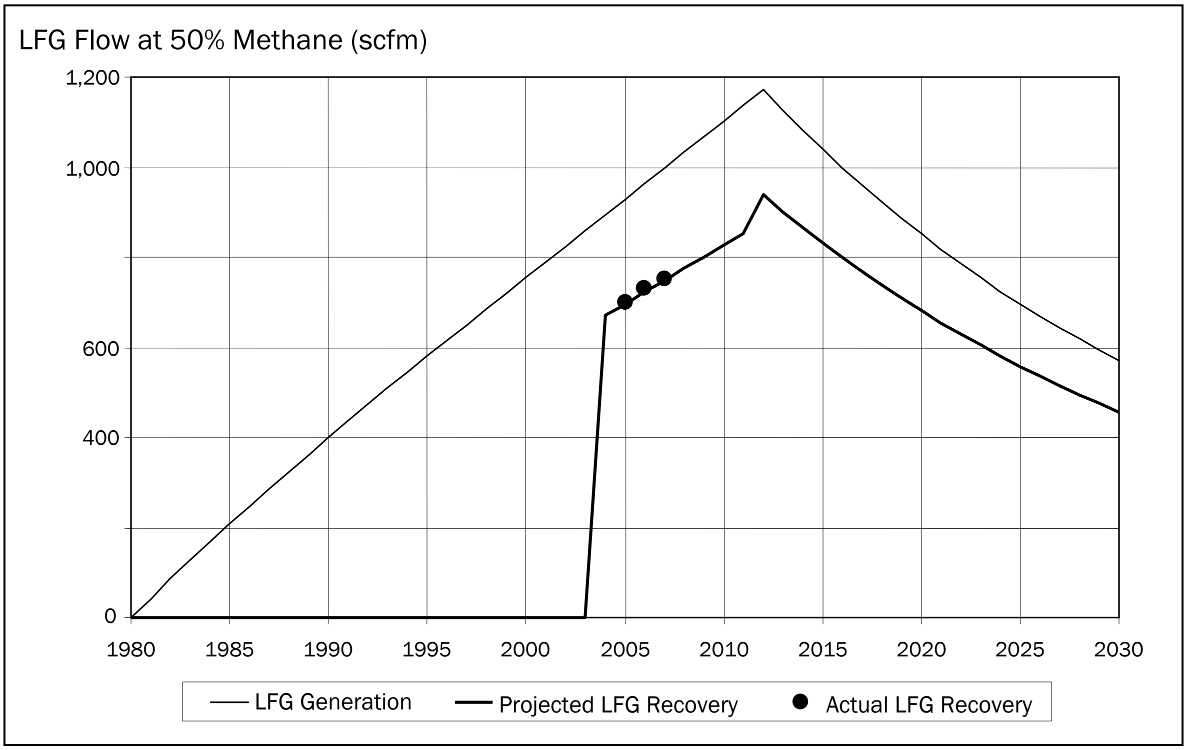
scfm: standard cubic feet per minute

The LFG recovery projections can also be displayed graphically. Both LFG generation and recovery can be displayed as line graphs in an "X-Y scatter" graph, showing LFG flow at 50 percent methane (Y-axis) in each year since the landfill opened (X-axis). For sites with operating collection systems and recovery data, the graph can be used to display actual recovery as dots. The graph can be used to compare projected to actual recovery for model calibration, which involves adjusting model k and L_0 values so that the projected LFG recovery rates closely match actual recovery.[4] Figure 2-2 shows a

[4] This handbook does not cover procedures for model calibration. LMOP recommends seeking the help of an experienced professional LFG modeler to perform model calibration.

sample model output graph for a landfill that opened in 1980, installed a gas collection system in 2003,[5] and will stop accepting waste at the end of 2011.

Figure 2-2. LFG Generation and Recovery Rates



Special Considerations for Bioreactor and Leachate Recirculation Landfills

In recent years, certain landfills have been designed and managed to deliberately introduce liquids into the waste in a controlled manner. This is done in order to speed up the waste decay process and shorten the time period of LFG generation. Landfills that achieve 40 percent moisture content in the waste through the controlled introduction of liquids (other than leachate and condensate) are considered "bioreactor" landfills according to EPA air regulations.[6] Landfills that introduce liquids (most commonly leachate and condensate) but achieve waste moisture contents less than 40 percent are considered "leachate recirculation" landfills. Bioreactor studies conducted by EPA's Office of Research and Development provide additional information.

The introduction of liquids into the landfill causes significant increases in waste decay rates and k values. This increase in k will cause gas generation to increase more rapidly while the landfill is receiving waste and decrease more rapidly once disposal stops, but will not change total LFG generation over the long term. Because only the rate of LFG generation is affected, L_0 values should theoretically be unaffected by liquids introduction. LandGEM provides a default k value of 0.7 for modeling bioreactor landfills (i.e., the "inventory wet" value). LMOP, however, recommends assigning

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[5] LFG recovery starts at known or projected date of the installation of the gas collection and control system.

[6] "Bioreactor" is defined in the municipal solid waste landfill National Emission Standards for Hazardous Air Pollutants, 40 CFR part 63, subpart AAAA.

a k value of 0.3 for bioreactors based on a University of Florida study completed shortly after LandGEM was released. No single k value is recommended or appropriate for leachate recirculation landfills because the impact of leachate recirculation on LFG generation varies depending on the amount of liquids added and the moisture content of waste achieved.

Sometimes, only a portion of a landfill's total site is designed and operated as a bioreactor or leachate recirculation landfill. In such cases, the bioreactor or leachate recirculation portion should be modeled separately from the remainder of the site, using waste disposal inputs for these areas only.

2.3 Model Limitations

Various factors can affect the accuracy of LFG recovery projections:

- *Limited or poor quality disposal data*. Significant model error can be introduced if good disposal data are not available.
- *Atypical waste composition*. Waste composition data are often not available to determine if unusual waste composition is a cause of model inaccuracy.
- *Poor quality flow data and/or inaccurate estimates of collection efficiency used for model calibration.* Model calibration requires both accurate estimates of collection efficiency and good quality flow data that is representative of long-term average recovery.
- *Inaccurate assumptions*. Inaccurate assumptions about variables such as future disposal rates, site closure dates, wellfield buildout, expansion schedules, or collection efficiencies can result in large errors in predicting future recovery.
- *Limitations due to the structure of LandGEM*. For example, LandGEM cannot accommodate changes in k or L_0 values in the same model run. Changing landfill conditions that cannot be modeled as a result of this limitation include the following:
  - Application of liquids to existing waste
  - Variations in waste composition over time
  - Installation of a geomembrane cover

The LFG modeler should be aware of the potential for model error due to the above-listed factors and use appropriately conservative model inputs to avoid significant overestimation of LFG recovery. Accurate estimates that do not overestimate recoverable methane are critical to the proper design and financial success of LFG energy projects.

3. Project Technology Options

Chapter Overview

The goal of a landfill gas (LFG) energy project is to convert LFG into a useful energy form, such as electricity, steam, heat, vehicle fuel, or pipeline quality gas. Several technologies can be used to maximize LFG when producing these forms of energy, the most prevalent of which are:

- Power production/cogeneration
- Direct use of medium-British thermal unit (Btu) gas
- Upgrade to vehicle fuel or pipeline-quality (high-Btu) gas

Each of these options has three basic components: a gas collection system and backup flare; a gas treatment system; and an energy recovery system.

The best type of project for a particular landfill will depend upon a number of factors, including existence of an available energy market, project costs, potential revenue sources, and many technical considerations.

This chapter provides a brief overview of the technologies and outlines the major characteristics of energy recovery systems, including the technical issues for determining a project's feasibility related to direct use, power production, and upgrade to vehicle fuel or pipeline quality gas. The chapter concludes with a discussion of how best to choose among the potential energy recovery technologies.

Tables 3-1 and 3-2 show the breakdown of technologies used in LFG electricity and direct-use projects in 2008.

Table 3-1. Technologies for LFG Electricity Projects

Project Technology	Number of Projects*
Internal combustion engine	249
Gas turbine	28
Cogeneration	20
Microturbine	14
Steam turbine	15
Combined cycle	6
Stirling cycle engine	2

* Projects listed as operational in the Landfill Methane Outreach Program (LMOP) database as of October 2008.

Table 3-2. Technologies for Direct-Use Projects

Project Technology	Number of Projects*
Boiler	52
Direct thermal	36
Leachate evaporation	17
High-Btu	15
Greenhouse	4
Alternative fuel (compressed natural gas or liquefied natural gas)	3
Medium-Btu gas injected into natural gas pipeline	1

* Projects listed as operational in the LMOP database as of October 2008.

3.1 Gas Collection System and Flare

Typical LFG collection systems have three central components: collection wells or trenches; a condensate collection and treatment system; and a blower. In addition, most landfills with energy recovery systems include a flare for the combustion of excess gas and for use during equipment downtimes. Each of these components is described below, followed by a brief discussion of collection system and flare costs.

Gas Collection Wells and Horizontal Trenches

Gas collection typically begins after a portion of a landfill (called a cell) is closed.[1] Collection systems can be configured as either vertical wells or horizontal trenches. Some collection systems use a combination of vertical wells and horizontal trenches. Well-designed systems of either type are effective in collecting LFG. The design chosen depends on site-specific conditions and the timing of LFG collection system installation.

Figure 3-1 illustrates the design of a typical vertical LFG extraction well, and Figure 3-2 shows a typical horizontal LFG collection system. Regardless of whether wells or trenches are used, each wellhead is connected to lateral piping, which transports the gas to a main collection header, as illustrated in Figure 3-3. Ideally, the collection system should be designed so that the operator can monitor and adjust the gas flow if necessary.

[1] A proper landfill final cover will allow for a more efficient and effective operation of the LFG collection system.

Figure 3-1. Typical LFG Extraction Well

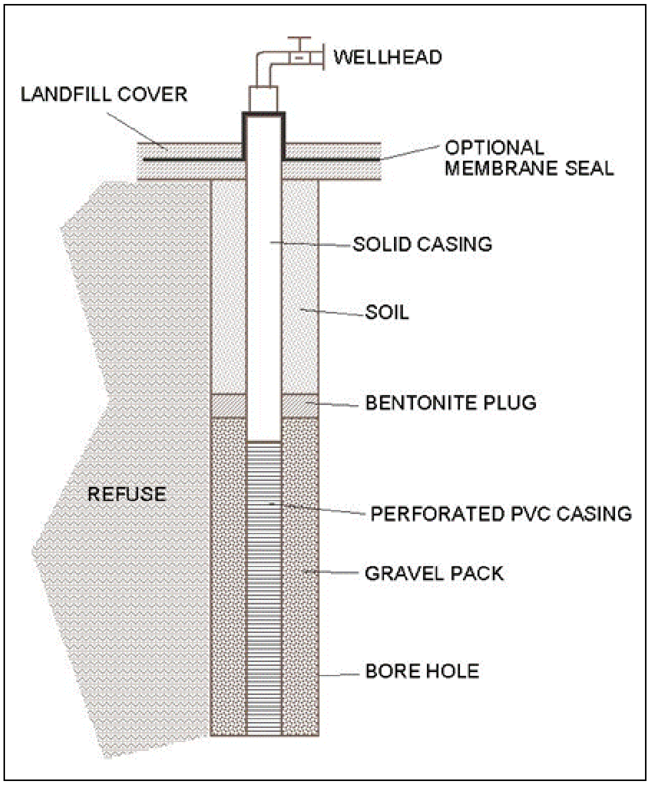


Figure 3-2. Typical LFG Collection System With Horizontal Trenches

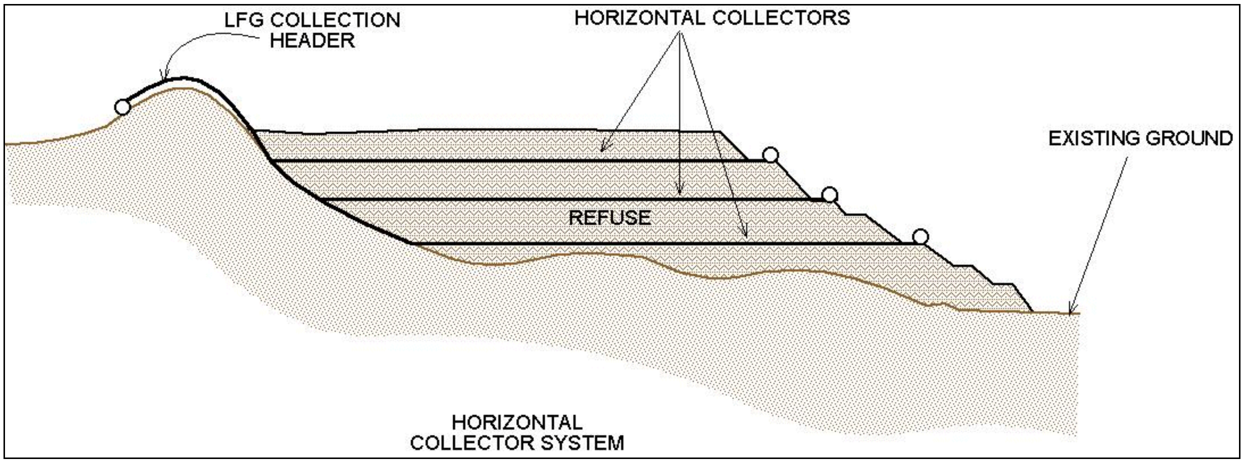
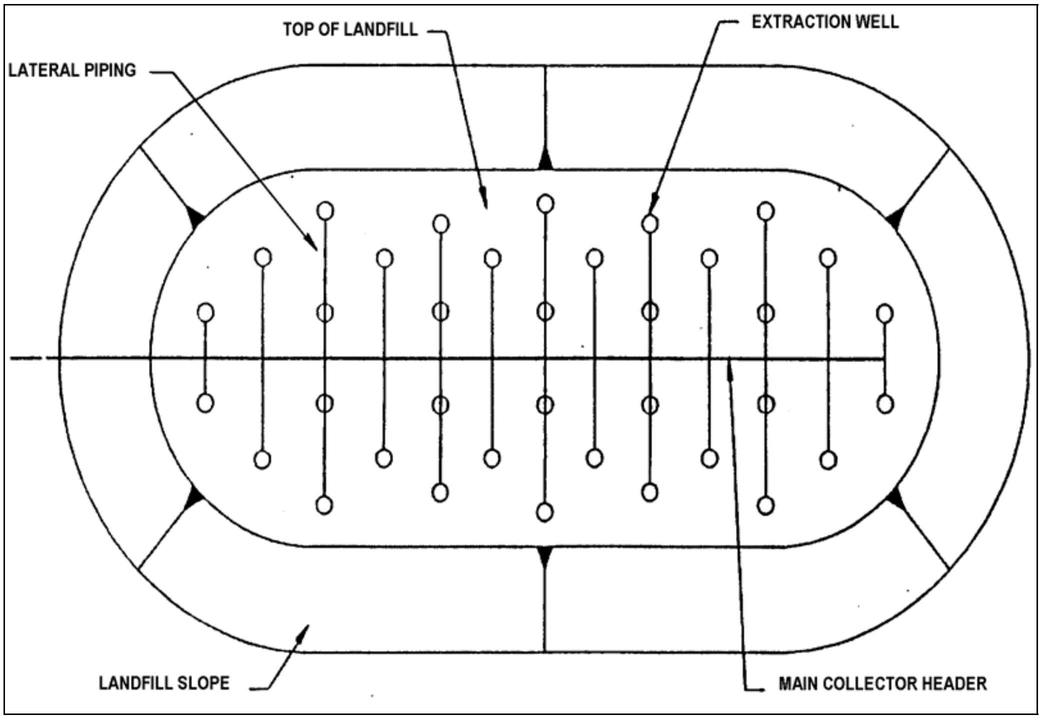


Figure 3-3. Sample LFG Extraction Site Plan



Condensate Collection

Condensate forms when warm gas from the landfill cools as it travels through the collection system. If condensate is not removed, it can block the collection system and disrupt the energy recovery process. Techniques for condensate collection and treatment are described in Section 3.2.

Blower

A blower is necessary to pull the gas from the collection wells into the collection header, and convey the gas to downstream treatment and energy recovery systems. The size, type, and number of blowers needed depend on the gas flow rate and distance to downstream processes.

Flare

A flare is a device for igniting and burning the LFG. Flares are a component of each energy recovery option because they may be needed to control LFG emissions during energy recovery system startup and downtime and to control gas that exceeds the capacity of the energy conversion equipment. In addition, a flare is a cost-effective way to gradually increase the size of the energy recovery system at an active landfill. As more waste is placed in the landfill and the gas collection system is expanded, the flare is used to control excess gas between energy conversion system upgrades (e.g., before addition of another engine).

Flare designs include open (or candlestick) flares and enclosed flares. Enclosed flares are more expensive but may be preferable (or required by state regulations) because they provide greater control of combustion conditions, allow for stack testing, and might achieve slightly higher combustion efficiencies than open flares. They can also reduce noise and light nuisances.

Collection System Costs

Total collection system costs vary widely, based on a number of site-specific factors. For example, if the landfill is deep, collection costs tend to be higher because well depths will need to be increased. Collection costs also increase with the number of wells installed. The estimated capital for collection systems (including flares) at typical landfills ranges from $18,000 to $24,000 per acre, assuming one well is installed per acre. The annual operation and maintenance (O&M) costs for collection systems (including one flare) are $4,000 to $6,000 per well. Flaring costs have been incorporated into these estimated capital and operating costs of LFG collection systems, since excess gas may need to be flared at any time, even if an energy recovery system is installed.

3.2 LFG Treatment Systems

After the LFG has been collected and before it can be used in a conversion process, it must be treated to remove condensate not captured in the condensate removal systems, particulates, and other impurities. Treatment requirements depend on the end use application. The focus of this section is treatment conducted prior to direct-use and electricity projects. Minimal treatment is required for direct use of gas in boilers, furnaces, or kilns. Treatment systems for LFG electricity projects typically include a series of filters to remove contaminants that could damage engine and turbine components and reduce system efficiency.

The more extensive treatment required to produce high-Btu gas for injection into natural gas pipelines or production of alternative fuels is discussed in Section 3.5.

The cost of gas treatment depends on the gas purity requirements of the end use application. The cost of a system to filter the gas and remove condensate for direct use of medium-Btu gas or for electric power production is considerably less than the cost of a system that must also remove contaminates such as siloxane and sulfur that are present at elevated levels in some LFG.

Types of Treatment Systems

Treatment systems can be divided into primary treatment processing and secondary treatment processing. Most primary processing systems include de-watering and filtration to remove moisture and particulates. Dewatering can be as simple as physical removal of free water or condensate in the LFG (often referred to as “knockout” devices). However, it is common in new projects to remove water vapor or humidity in the LFG by using gas cooling and compression. Typical temperatures for gas cooling are from 35 to 50°F. Gas compression is commonly specified by the distance to the energy recovery systems and by their input pressure requirements, and commonly ranges from 10 to over 100 pounds per square inch gauge (psig). These technologies have been in use for many years and are now relatively standard elements of active LFG collection systems. Secondary treatment systems are designed to provide much greater gas cleaning than is possible using primary systems alone. Secondary treatment systems may employ multiple cleanup processes depending on the gas specifications of the end use. Such processes can include both physical and chemical treatments.

The type of secondary treatment depends on the constituents that need to be removed for the desired end use. Two of the trace contaminants that may have to be removed from LFG are:

- *Siloxanes:* Siloxanes are found in household and commercial products that find their way into solid waste and wastewater (a concern for landfills that take wastewater treatment sludge). The siloxanes in the landfill volatilize into the LFG and are converted to silicon dioxide when the LFG is combusted. Silicon dioxide (the main constituent of sand) is a white substance that collects on the inside of the internal combustion engines and gas turbine components and on boiler tubes, reducing the performance of the equipment and resulting in significantly higher maintenance cost.

- *Sulfur compounds:* These compounds, which include sulfides/disulfides (e.g., hydrogen sulfide), are corrosive in the presence of moisture.

The most common technologies used for secondary treatment are adsorption and absorption. Adsorption involves the physical adsorption of the contaminant onto the surface of an adsorbent such as activated carbon or silica gel. Adsorption has been a common technology for removing siloxanes from LFG. Absorption (or scrubbing) involves the chemical/physical reaction of a contaminant with a solvent or solid reactant. Absorption has been a common technology for removing sulfur compounds from LFG.

Advanced treatment technologies that remove carbon dioxide, non-methane organic compounds (NMOCs), and a variety of other contaminants in LFG to produce a high-Btu gas (typically at least 96 percent methane) are discussed in Section 3.5.

3.3 Electricity Generation

Producing electricity from LFG continues to be the most common beneficial use application, accounting for about two-thirds of all U.S. LFG energy projects. Electricity can be produced by burning LFG in an internal combustion engine, a gas turbine, or a microturbine. Each of the following subsections describes one of these technologies, suggests its advantages and disadvantages, and provides some cost guidance.

Internal Combustion Engines

The internal combustion engine, shown in Figure 3-4, is the most commonly used conversion technology in LFG applications; more than 70 percent of all existing LFG electricity projects use them. The reason for such widespread use is their relatively low cost, high efficiency, and good size match with the gas output of many landfills. Internal combustion engines have generally been used at sites where gas quantity is capable of producing 800 kilowatts (kW) to 3 megawatts (MW), or where sustainable LFG flow rates to the engines are approximately 0.4 to 1.6 million cubic feet per day (cfd) at 50 percent methane. Multiple engines can be combined together for projects larger than 3 MW.

Figure 3-4. Internal Combustion Engines

Table 3-3 provides examples of available sizes of internal combustion engines.

Table 3-3. Internal Combustion Engine Sizes

Engine Size	Gas Flow (in cfm at 50% Methane)
540 kW	204
633 kW	234
800 kW	350
1.2 MW	500

cfm: cubic feet per minute

Internal combustion engines are relatively efficient at converting LFG into electricity, achieving efficiencies in the range of 25 to 35 percent. Even greater efficiencies are achieved in combined heat and power (CHP) applications where waste heat is recovered from the engine cooling system to make hot water, or from the engine exhaust to make low-pressure steam. For more information about CHP, which can be used with internal combustion engines, turbines, or microturbines, see the CHP Partnership's Biomass CHP Catalog of Technologies and the Catalog of CHP Technologies.

> The following case studies developed by LMOP provide examples of a large (i.e., 10 MW) and an average size (i.e., 3-4 MW) internal combustion engine project:
>
> - Green Knight Energy Development Project (10 MW)
> - Dairyland LFG Energy Project (4 MW)

Gas Turbines

Gas turbines, shown in Figure 3-5, are typically used in larger LFG energy projects, where LFG volumes are sufficient to generate a minimum of 3 MW, and typically more than 5 MW (i.e., where gas flows exceed a minimum of 2 million cfd). This technology is competitive in larger LFG electric generation projects because, unlike most internal combustion engine systems, gas turbine systems have significant economies of scale. The cost per kW of generating capacity drops as gas turbine size increases, and the electric generation efficiency generally improves as well.

Figure 3-5. Gas Turbines

Simple-cycle gas turbines applicable to LFG energy projects typically achieve efficiencies of 20 to 28 percent at full load; however, these efficiencies drop substantially when the unit is running at partial load. Combined-cycle configurations, which recover the waste heat in the gas turbine exhaust to make additional electricity, can boost the system efficiency to approximately 40 percent, but this configuration is also less efficient at partial load. A primary disadvantage of gas turbines is that they require high gas compression (165 psig or greater), causing high parasitic load loss. This means that more of the plant's power is required to run the compression system, compared to other generator options. Advantages of gas turbines are that they are more resistant to corrosion damage than internal combustion engines and have lower nitrogen oxides emission rates. In addition, gas turbines are relatively compact and have low O&M costs compared to internal combustion engines. However, a higher level of LFG treatment for the removal of siloxanes may be required, since siloxane buildup can have a negative effect on gas turbine operation. This additional gas treatment increases project costs.

> An example of a gas turbine project is at the Arlington Landfill in Arlington, Texas where LFG is piped four miles to the Arlington Wastewater Treatment Plant and used to fuel two 5.2 MW gas turbine generators.

Microturbines[2]

Microturbines (Figure 3-6) have been sold commercially in landfill and other biogas applications since early 2001. In general, microturbine project costs have been more expensive on a dollar-per-kW installed capacity basis than internal combustion engine projects. Some of the reasons projects have selected microturbine technology instead of internal combustion engines include:

- LFG availability at less than the 300 cfm required for typical internal combustion engines (although recently, small internal combustion engines have become available in this size range).
- Lower percent methane as microturbines can function with as little as 35 percent methane.
- Low nitrogen oxides emissions desired.
- Ability to add and remove microturbines as available gas quantity changes.
- Relatively easy interconnection due to lower generation capacity.

Figure 3-6. Microturbine

In earlier microturbine applications, LFG was not treated sufficiently; this resulted in system failures. Typically, LFG treatment to remove moisture, siloxanes, and other contaminants is required for microtubines. Treatment includes the following components:

- Inlet moisture separator.
- Rotary vane type compressor.
- Chilled water heat exchanger (reducing LFG temperature to 40°F).
- Coalescing filter.

[2] Wang, Benson, Wheless. 2003. *Microturbine Operating Experience at Landfills.* SWANA 26th Annual Landfill Gas Symposium (2003), Tampa, Florida.

- LFG reheat exchanger (to add 20 to 40ºF above dew point).

- Further treatment of the moisture-free LFG in vessels charged with activated carbon and/or other media (optional).

Microturbines come in sizes of 30, 70, and 250 kW. Projects should use the larger-capacity microturbines where power requirements and LFG availability can support them. The following benefits can be gained by using a larger microturbine:

- Reduced capital cost (on a dollar-per- kW of installed capacity basis) for the microturbine itself.

- Reduced maintenance cost.

- Reduced balance of plant installation costs — a reduction in the number of microturbines to reach a given capacity will reduce piping, wiring, and foundation costs.

- Improved efficiency — the heat rate of the 250 kW microturbine is expected to be about 3.3 percent better than the 70 kW and about 12.2 percent better than the 30 kW microturbine.

An example of a microturbine project is the Lopez Canyon LFG Energy Project.

Electricity Generation Cost Summary

The costs of energy generation using LFG vary greatly; they depend on many factors including the type of electricity generation equipment, its size, the necessary compression and treatment system, and the interconnect equipment. Table 3-4 presents examples of typical costs for several technologies, including costs for a basic gas treatment system typically used with each technology.

Table 3-4. Examples of Typical Costs

Technology	Typical Capital Costs ($/kW)*	Typical Annual O&M Costs ($/kW)*
Internal combustion engine (> 800 kW)	$1,300	$160
Small internal combustion engine (< 1 MW)	$1,700	$180
Gas turbine (> 3 MW)	$970	$110
Microturbine (< 1 MW)	$5,400	$350

* 2007 dollars.

kW: kilowatt

MW: megawatt

A growing problem for all electricity generation projects is the accumulation of siloxanes. Before an LFG electric generation project is installed, the LFG should be tested to determine the level of siloxanes present. Even electric generation projects that have been operating without a siloxane issue may one day encounter problems if the levels of siloxanes in the landfill and the LFG increase. Depending on the level of siloxanes, gas treatment is required before LFG is introduced to the electricity generating equipment. The most common type of treatment is activated carbon filtration (adsorption), although other adsorption media, such as silica gel, are being tested. Subzero refrigeration and liquid scrubbing are other gas treatment technologies that can remove siloxanes.

3.4 Direct Use of Medium-Btu Gas

Boilers, Dryers, and Kilns

The simplest and often most cost-effective use of LFG is as a medium-Btu fuel for boiler or industrial process use (e.g., drying operations, kiln operations, and cement and asphalt production). In these projects, the gas is piped directly to a nearby customer where it is used in new or existing combustion equipment (see Figure 3-7) as a replacement or supplementary fuel. Only limited condensate removal and filtration treatment is required, but some modifications of existing combustion equipment might be necessary.

Because of the cost of natural gas, this technology has gained popularity in recent years. The economics of longer pipelines have become more favorable. For more cost information see Chapter 4.

The energy users' energy requirements are an important consideration when evaluating the sale of LFG for direct use. Because no economical way to store LFG exists, all gas that is recovered must be used as available, or it is essentially lost, along with associated revenue opportunities. The ideal gas customer, therefore, will have a steady annual gas demand compatible with the landfill's gas flow. When a landfill does not have adequate gas flow to support the entire needs of a facility, LFG can still be used to supply a portion of the needs. For example, in some facilities, only one piece of equipment (e.g., a main boiler) or set of burners is dedicated to burning LFG. These facilities might also have equipment that can use LFG along with other fuels. Other facilities blend LFG with other fuels.

Figure 3-7. Boiler and Cement Kiln

Table 3-5 gives the expected annual gas flows on a million Btu (MMBtu) per year basis from landfills of different sizes. While actual gas flows will vary based on waste age, composition, moisture, and other factors, these numbers can be used as a first step toward determining the compatibility of customer gas requirements and LFG output. A rule of thumb for comparing boiler fuel requirements to LFG output is that approximately 8,000 to 10,000 pounds per hour of steam can be generated for every 1 million metric tons of waste-in-place at a landfill; accordingly, a 5 million metric ton landfill can support the needs of a large facility requiring about 50,000 pounds per hour of steam for process use. Prior to pursuing a LFG energy direct-use project, however, LFG flow should be measured and/or gas modeling should be conducted as described in Chapter 2, to refine the estimate of LFG flow and energy available from the landfill.

Table 3-5. LFG Flows Based on Landfill Size

Landfill Size (Metric Tons Waste-in-Place)	LFG Output (MMBtu/yr)	Steam Flow Potential (lbs/hr)
1,000,000	100,000	10,000
5,000,000	450,000	45,000
10,000,000	850,000	85,000

MMBtu/yr: million Btu per year

If an ideal customer is not accessible, it may be possible to create a steady gas demand by serving multiple customers whose gas requirements are complementary. For example, an asphalt producer's summer gas load could be combined with a municipal building's winter heating load to create a year-round demand for LFG.

Equipment modifications or adjustments may be necessary to accommodate the lower Btu value of LFG, and the costs of modifications will vary. If retuning the boiler burner is the only modification required, costs will be minimal.

The costs associated with retrofitting boilers will vary from unit to unit depending on boiler type, fuel use, and age of unit. Typical tiers of retrofits include:

- Incorporation of LFG in a unit that is co-firing with other fuels, where automatic controls are required to sustain a co-firing application or to provide for immediate and seamless fuel switching in the event of a loss in LFG pressure to the unit. This retrofit will ensure uninterruptible steam supply. Overall costs can range from $200,000 to $400,000 and include all retrofit costs (burner modifications, fuel train, process controls).

- Modification of a unit where surplus or back-up steam supply is available and uninterruptible steam supply from the unit is not required if loss of LFG pressure to the unit occurs. In this case, manual controls are implemented and the boiler operating system is not integrated in an automatic control system. Overall costs can range from $100,000 to $200,000.

Another option is to improve the quality of the gas to such a level that the boiler will not require a retrofit. The gas is not required to have a Btu value as high as pipeline-quality, but the quality must be between medium and high. This option reduces the cost of a boiler retrofit and subsequent maintenance costs associated with cleaning because of deposits associated with use of medium-Btu LFG.

A potential problem for boilers is the accumulation of siloxanes. The presence of siloxanes in the LFG causes a white substance to build up on the boiler tubes. Operators who experience this problem can choose either to perform routine cleaning of the boiler tubes or to install a gas treatment system to reduce the amount of siloxanes in the LFG prior to delivery to the boiler. The most common type of treatment is activated carbon filtration (adsorption), although other media such as silica gel are being tested. Subzero refrigeration and liquid scrubbing are other treatment technologies that can remove siloxanes.

For more information about the use of LFG in boilers, see the LMOP fact sheet on boilers.

A case study of a boiler adaptation at the NASA Goddard Flight Center also provides information about LFG use in boilers.

The following case study examples of direct thermal projects can be found on LMOP's Web site:

- Kilns
  St. John's LFG Energy Project
- Dryers
  Clay Mine LFG Application
  Buncombe County Sludge Drying Project
- Process Heaters
  Wayne Township LFG Energy Project for Jersey Shore Steel

Infrared Heaters

Infrared heating using LFG (Figure 3-8) is ideal when a facility with space heating needs is located near a landfill. Infrared heating creates high-intensity energy that is safely absorbed by surfaces that warm up. In turn, these surfaces release heat into the atmosphere and raise the ambient temperature. Infrared heating, using LFG as a fuel source, has been successfully employed at several landfill sites in Europe, Canada, and the United States. Infrared heaters require a small amount of LFG to operate and are relatively inexpensive and easy to install. Current operational projects use between 20 and 50 m^3/hr (12 to 30 cfm). Infrared heaters do not require pretreatment of the LFG, unless there are siloxanes in the gas.

The cost of infrared heaters depends on the area to be heated. One heater is needed for every 500 to 800 square feet. The cost of each heater, in 2007 dollars, is approximately $3,000. In addition, the cost of the interior piping to connect the heaters within the building ceilings is approximately $20,000 to $30,000.

An example of the use of infrared heaters in maintenance facilities is at I-95 Landfill in Virginia.

Figure 3-8. Infrared Heaters

Greenhouses

Greenhouses are another application for LFG (Figure 3-9). LFG can be used to provide heat for greenhouses and also to heat water used in hydroponic plant culture. LFG can be used in a microturbine to power the grow lights and the waste heat can be used for heating the greenhouse or water.

Figure 3-9. Greenhouse

Several greenhouses have been constructed near landfills in order to take advantage of the energy cost savings, for example at the Rutgers University EcoComplex Greenhouse.

The costs related to using LFG in greenhouses depend on how the LFG will be used. If the grow lights are powered by a microturbine, then the project costs would be similar to an equivalent microturbine LFG energy project. If LFG is used to heat the greenhouse, the cost incurred would be the cost of the piping and of the technology used, such as boilers. See the appropriate technology section in this chapter and Chapter 4 for cost information.

Artisan Studios

Artisan studios with energy-intensive activities such as glass-blowing, metalworking, and pottery Figure 3-10) offer another opportunity for the beneficial use of LFG. This application does not require a large amount of LFG and can be coupled with a commercial project. For example, a gas flow of 100 cfm is sufficient for a studio that houses glass-blowing, metalworking, or pottery.

> The first artisan project to use LFG was at the EnergyXchange at the Yancey-Mitchell Landfill in North Carolina. At this site, LFG is used to power two craft studios, four greenhouses, a gallery, and a visitor center.

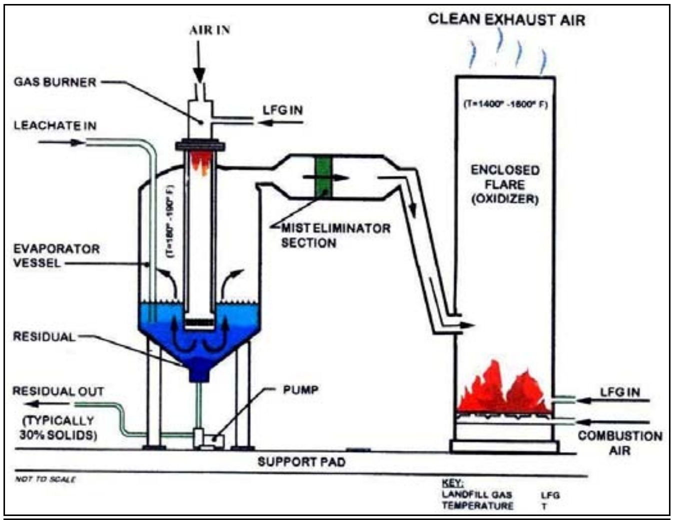
Figure 3-10. LFG-Powered Glass Studio

Leachate Evaporation

Leachate evaporation (Figure 3-11) is a good option for landfills where leachate disposal in a publicly owned treatment works (POTW) plant is unavailable or expensive. Evaporators are available in sizes to treat 10,000 to 20,000 gallons of leachate per day. LFG is used to evaporate leachate to a more concentrated and more easily disposed effluent volume. Capital costs range from $300,000 to $500,000. O&M costs range from $70,000 to $95,000 per year.

> The Olympic View Landfill in Port Orchard, Washington, uses leachate evaporation.

Figure 3-11. Leachate Evaporation Diagram and Photo



Biofuel Production

LFG can be used to heat the boilers in plants that produce biofuels including biodiesel and ethanol. In this case, LFG is used directly as a fuel to offset another fossil fuel. Alternatively, LFG can be used as feedstock when it is converted to methanol for biodiesel production.

> One example of such a project is located in Denton, Texas. The City of Denton collects used vegetable oil and processes it, using LFG as a fuel source, to produce biodiesel to operate its vehicle fleet.

3.5 Conversion to High-Btu Gas[3]

LFG can be used to produce the equivalent of pipeline-quality gas (natural gas), compressed natural gas (CNG), or liquefied natural gas (LNG). Pipeline-quality gas can be sold into a natural gas pipeline used for an industrial purpose. CNG and LNG can be used to fuel vehicles at the landfill (e.g., water trucks, earthmoving equipment, light trucks, autos), fuel refuse-hauling tucks (long haul refuse transfer trailers and route collection trucks), and supply the general commercial market (Figure 3-12).

[3] Pierce, J. SCS Engineers. 2007. *Landfill Gas to Vehicle Fuel: Assessment of Its Technical and Economic Feasibility.* SWANA 30th Annual Landfill Gas Symposium (March 4 to 8, 2007), Monterey, California.

Figure 3-12. LNG-Powered Trucks and LNG Station

LFG can be converted into a high-Btu gas by increasing its methane content and, conversely, reducing its carbon dioxide, nitrogen, and oxygen content. In the United States, three methods have been commercially employed (i.e., beyond pilot testing) to remove carbon dioxide from LFG:

- Membrane separation
- Molecular sieve (also known as pressure swing adsorption or PSA)
- Amine scrubbing

All three methods focus on removing carbon dioxide, not oxygen or nitrogen. The preferred method to reduce the level of oxygen and nitrogen in LFG to pipeline specifications is to design and operate the gas collection system (wellfield) properly. The primary cause for the presence of oxygen and nitrogen in LFG is air intrusion: LFG collection systems create a vacuum, and air can be drawn through the surface of the landfill and into the gas collection system. Air intrusion can often be minimized by adjusting well vacuums and repairing leaks in the landfill cover. In some instances, air intrusion can be managed by sending LFG from the interior wells directly to the high-Btu process, and sending LFG from the perimeter wells (which often have higher nitrogen and oxygen levels) to another beneficial use or emissions control device.

Membrane separation can achieve some incidental oxygen removal, but nitrogen — which represents the bulk of the non-methane/non-carbon dioxide fraction of LFG — is not removed. A molecular sieve can be configured to remove nitrogen by proper selection of media. Nitrogen removal, in addition to carbon dioxide removal requires a two-stage molecular sieve (PSA).

Amine Scrubbing Process. Selexol has been the most common amine used in amine scrubbing systems to convert LFG to high-Btu gas. A typical Selexol-based plant employs the following steps:

- LFG compression (using electric drive, LFG-fired engine drive, or product gas–fired engine drive).
- Moisture removal using refrigeration.
- Hydrogen sulfide removal in a solid media bed (using an iron sponge or a proprietary media).
- NMOC removal in a primary Selexol absorber.
- Carbon dioxide removal in a secondary Selexol absorber.

In a Selexol absorber tower, the LFG is placed in contact with the Selexol liquid. Selexol is a physical solvent that preferentially absorbs gases into the liquid phase. NMOCs are generally hundreds to thousands of times more soluble than methane. Carbon dioxide is about 15 more times soluble than methane. Solubility also is enhanced with pressure, facilitating the separation of NMOCs and carbon dioxide from methane.

Molecular Sieve Process. A typical molecular sieve plant employs the compression, moisture removal, and hydrogen sulfide removal steps listed under the amine scrubbing process, but relies on vapor phase activated carbon and a molecular sieve for NMOC and carbon dioxide removal, respectively. Once the activated carbon is exhausted, it can be regenerated on site through a depressurizing heating and purge cycle. The process is known as thermal swing absorption.

Membrane Separation Process. A typical membrane plant employs compression, moisture removal, and hydrogen sulfide removal steps, but relies upon activated carbon to remove NMOCs and membranes to remove carbon dioxide. Activated carbon removes NMOCs and protects the membranes. The membrane process exploits the fact that gases, under the same conditions, will pass through polymeric membranes at differing rates. Carbon dioxide passes through the membrane approximately 20 times faster than methane. Pressure is the driving force for the separation process. Early membrane plants used “high” pressure membranes. Newer plants use “low” pressure membranes.

An example of a pipeline-quality gas project is the one in City of Fort Smith, Arkansas.

CNG

For CNG production, the membrane separation and molecular sieve processes scale down more economically to smaller plants. For this reason, these technologies are more likely to be used for CNG production than the Selexol (amine scrubbing) process.

The Los Angeles County Sanitation District's LFG to CNG project at Puente Hills Landfill has been operating for more than 10 years. It converts an inlet flow of 250 standard cubic feet per minute (scfm) at 55 percent methane to 100 scfm of CNG at 96 percent methane. The product is equivalent to about 1,000 gallons of gasoline equivalent per day. At a fuel economy of 20 miles per gallon, the facility can support about 20,000 trip miles per day.

The process chain for CNG production at Puente Hills is as follows:

- LFG compression and moisture removal. Compression is undertaken in multiple stages to reach 525 psi.
- Vapor phase activated carbon.
- Gas heating to 140°F.
- Three stages of membrane separation.
- Multi-stage compression of the product gas to 3,600 psi.
- Compressed gas storage facilities.
- A fuel dispenser to dispense 3,000 psi CNG.

Construction of the Puente Hills CNG facility cost $1.8 million (cost escalated to 2007 dollars). The Puente Hills project is a relatively small demonstration project and its cost is therefore not representative of a larger project.[4] Table 3-6 shows estimated total costs of CNG production for membrane separation processes capable of handling various gas flows.

Table 3-6. Cost of CNG Production*

Inlet LFG (scfm)	Plant Size (GGE/day)	Cost ($/GGE)
250	1,000	$1.40
500	2,000	$1.13
1,250	5,000	$0.91
2,500	10,000	$0.82
5,000	20,000	$0.68

* Costs escalated to 2007 dollars from Wheless, E., et al. 1994. "Processing and Utilization of Landfill Gas as a Clean Alternative Vehicle Fuel." SWANA 17th Annual Landfill Gas Symposium (March 22 to 24, 1994), Long Beach, CA.

GGE: gallons of gasoline equivalent
scfm: standard cubic feet per minute

More information about the Puente Hills CNG project is available on LMOP's Web site.

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[4] Pierce, J. SCS Engineers. 2007. *Landfill Gas to Vehicle Fuel: Assessment of Its Technical and Economic Feasibility*. SWANA 30th Annual Landfill Gas Symposium (March 4 to 8, 2007), Monterey, California.

LNG

If LFG is first converted to CNG, it can then be liquefied to produce LNG using conventional natural gas liquefaction technology. When considering this technology, two factors must be considered:

- Carbon dioxide freezes at a temperature higher than methane liquefies. To avoid "icing" in the plant, the product CNG must have as low a level of carbon dioxide as possible. This low carbon dioxide requirement would favor the molecular sieve over the membrane process, or at least favor upgrading the gas produced by the membrane process with a molecular sieve.

- Natural gas liquefaction plants have generally been "design to order" facilities that process large quantities of LNG. A few manufacturers have begun offering smaller, pre-packaged liquefaction plants. Even these "small" plants have design capacities of 10,000 gallons/day or greater.

Unless the nitrogen and oxygen content of the LFG is very low, the process chain must include nitrogen and oxygen removal steps. Liquefier manufacturers desire an inlet gas to have less than 0.5 percent oxygen, citing explosion concerns. Nitrogen needs to be limited to obtain the desired LNG methane content of 96 percent.

The cost of LNG production is estimated to be $0.65/gallon for a plant producing 15,000 gallons/day of LNG. A plant producing 15,000 gallons/day of LNG requires 3,000 scfm of LFG and would require a capital investment approaching $20 million.[5]

3.6 Selection of Technology

The primary factor in choosing the right project configuration for a particular landfill is the projected expense versus potential revenue. In general, sale of medium-Btu gas to a nearby customer, which requires minimal gas processing and typically is tied to a retail gas rate rather an electric buyback rate, is the simplest and most cost-effective option. If a suitable customer is located nearby and is willing to purchase the gas, this option should be thoroughly examined. An energy user that requires gas 24 hours per day, 365 days a year, is the best match for an LFG energy project, since intermittent or seasonal LFG uses typically result in the wasting of gas during the off-periods. If no such customer exists, the landfill could use its energy resources to attract industry to locate near the landfill. The landfill should work with a local department of economic development to develop a strategy for this option.

> Some corporations are deciding to build facilities near landfills in order to take advantage of LFG as a reliable, renewable fuel that costs less than natural gas. An example is when Jenkins Brick decided to locate a new plant near the Veolia ES Star Ridge Landfill in Moody, Alabama.

[5] Pierce, J. SCS Engineers. 2007. *Landfill Gas to Vehicle Fuel: Assessment of Its Technical and Economic Feasibility.* SWANA 30th Annual Landfill Gas Symposium (March 4 to 8, 2007), Monterey, California.

Electricity generation may prove to be the best option if no nearby energy user can be found. The economics of an electric generation project depend largely on factors including the price at which the electricity can be sold, available tax credits, or other revenue streams such as renewable energy credits and carbon credits. If the purchasing utility pays only the avoided cost[6] for the electricity and no other revenue streams are available, an electric generation project may not be economically feasible. Fortunately, with the interest in renewable energy and the growing numbers of states with Renewable Portfolio Standards (RPS), electric generation projects are receiving better than avoided cost power purchase agreements (PPA).[7]

In addition to a favorable sales agreement (e.g., PPA) with the purchaser of the electricity, negotiating an acceptable interconnection agreement is important to a successful electric generation project. The interconnection agreement can be a large cost variable, and discussions with the utility should therefore begin early in the project.

If an electric generation project is selected, the next step is to choose the type of power generation. The preferred generator type depends on the amount of recoverable LFG, the expected quantity for at least 10 years, and the gas quality. If both heat or steam and electric power are needed forms of energy, then a CHP project may be the appropriate choice. Regardless of which generator type is used, the project will most likely need to be sized smaller than the amount of available gas to ensure full-load operation of equipment. Therefore the project likely will have excess gas that will have to be flared.

State and local air quality regulations and limits can also play a role in technology selection. Refer to local air regulations for determining restrictions on technologies. For example, internal combustion engines may not be able to comply with nitrogen oxides emission requirements and a gas turbine or microturbine may need to be used. Even gas turbines may require more extensive pretreatment of the gas and/or exhaust treatment to meet stringent emission limits for various pollutants.

Regions of the country with more stringent air regulations offer opportunities for an LFG to CNG or LNG project, because use of these fuels in landfill vehicles or refuse collection and transfer fleets in place of fossil fuels will lower emissions from these vehicles.

Table 3-7 shows a summary of the different LFG energy technologies discussed in this chapter. The table presents key advantages and disadvantages associated to each technology. It also shows the amount of LFG flow usually associated with each technology. For technology costs, which are also an important factor in selecting a technology, see Chapter 4.

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[6] Avoided costs are the costs the utility avoids, or saves, by not making the equivalent amount of electricity in one of their own facilities, and would include fuel costs and some operating costs, but not fixed costs.

[7] The most traditional and historically common structure for an LFG electricity project is to sell the electricity to an investor-owned utility (IOU), cooperative, or municipal entity through a PPA. Typically, the electricity, including energy and capacity, is sold to the IOU at a fixed price with some kind of escalation, or an indexed price based on an estimate of short run avoided cost, or a publicly available local market price mechanism. (See Chapter 5 for more information.)

Table 3-7. Summary of LFG Energy Technologies

Project	Technology	Advantages	Disadvantages	LFG Flow Range for Typical Projects (at Approx. 50% Methane)
Electricity	Internal combustion engine Sizing: 800 kW to 3 MW per engine	High efficiency compared to gas turbines and microturbines. Good size match with the gas output of many landfills. Relatively low cost on a per kW installed capacity basis when compared to gas turbines and microturbines. Efficiency increases when waste heat is recovered. Can add/remove engines to follow gas recovery trends.	Relatively high maintenance costs. Relatively high air emissions. Economics may be marginal in areas of the country with low electricity costs.	300 to 1,100 cfm; multiple engines can be combined for larger projects
	Gas turbine Sizing: 1 to 10 MW per gas turbine	Economies of scale, since the cost of kW of generating capacity drops as gas turbine size increases and the efficiency improves as well. Efficiency increases when heat is recovered. More resistant to corrosion damage. Low nitrogen oxides emissions. Relatively compact.	Efficiencies drop when the unit is running at partial load. Require high gas compression. High parasitic loads. Economics may be marginal in areas of the country with low electricity costs.	Exceeds minimum of 1,300 cfm; typically exceeds 2,100 cfm
	Microturbine Sizing: 30 to 250 kW per microturbine	Need lower gas flow. Can function with lower percent methane. Low nitrogen oxides emissions. Relatively easy interconnection. Ability to add and remove units as available gas quantity changes.	Require fairly extensive pre-treatment of LFG. Economics may be marginal in areas of the country with low electricity costs.	20 to 200 cfm

Table 3-7. Summary of LFG Energy Technologies

Project	Technology	Advantages	Disadvantages	LFG Flow Range for Typical Projects (at Approx. 50% Methane)
Direct Use Medium-Btu	Boiler, dryer, and process heater	Can utilize maximum amount of recovered gas flow. Cost-effective. Limited condensate removal and filtration treatment is required. Gas can be blended with other fuels.	Need to retrofit equipment or improve quality of gas. All recovered gas must be used or it is lost. Cost is tied to length of pipeline; energy user must be nearby.	Utilizes all available recovered gas
	Infrared heater	Limited condensate removal and filtration treatment is required. Relatively inexpensive. Easy to install. Does not require large amount of gas. Can be coupled with another energy project.	Seasonal use may limit LFG utilization.	Small quantities of gas, as low as 20 cfm
	Greenhouse	Can mix different technologies.	Seasonal use may limit LFG utilization.	Small quantities of gas
	Artisan studio	Does not require large amount of gas. Can be coupled with a commercial project.	Project economics may be limited without grant or other outside funding sources.	Small quantities of gas
	Leachate evaporation	Good option for landfill where leachate disposal is expensive.	High capital costs.	1,000 cfm is necessary to treat 1 gallon per minute of leachate
Direct Use High-Btu	Pipeline-quality gas	Can be sold into a natural gas pipeline.	Requires potentially expensive gas processing. Increased cost due to tight management of wellfield operation needed to limit oxygen and nitrogen intrusion into LFG.	600 cfm and up, based on currently operating projects
	CNG or LNG	Alternative fuels for vehicles at the landfill or refuse hauling trucks, and for supply to the general commercial market.	Requires potentially expensive gas processing. Increased cost due to tight management of wellfield operation needed to limit oxygen and nitrogen intrusion into LFG.	Dependent on project-specific conditions

4. Project Economics and Financing

Chapter Overview

Evaluating the economic feasibility of various landfill gas (LFG) energy project options, selecting the most viable alternative, and determining available financing for the project are integral steps in the project development process. This chapter provides guidance on the steps for performing an economic analysis and discusses the various financing alternatives available for LFG energy projects. This chapter includes:

- Information on typical capital and operation and maintenance (O&M) costs for LFG collection systems, LFG electricity projects, and direct-use projects, and discussion of factors that influence these costs.
- Information on potential revenue streams, financial incentives, and funding opportunities for LFG energy projects.
- Examples of preliminary financial evaluations of LFG energy projects.
- References to online documents and tools for further information.
- Discussion of project financing options.

Economic Evaluation Process

The first step in the evaluation process is to perform a preliminary economic feasibility assessment. This assessment will help determine if a project is right for the landfill in question, and if so, what project configuration should be considered in the next phases of evaluation. EPA's Landfill Methane Outreach Program (LMOP) provides the LFGcost-Web economic assessment tool to help Partners perform preliminary cost assessments. LMOP can also provide assistance in customizing preliminary LFGcost analyses.

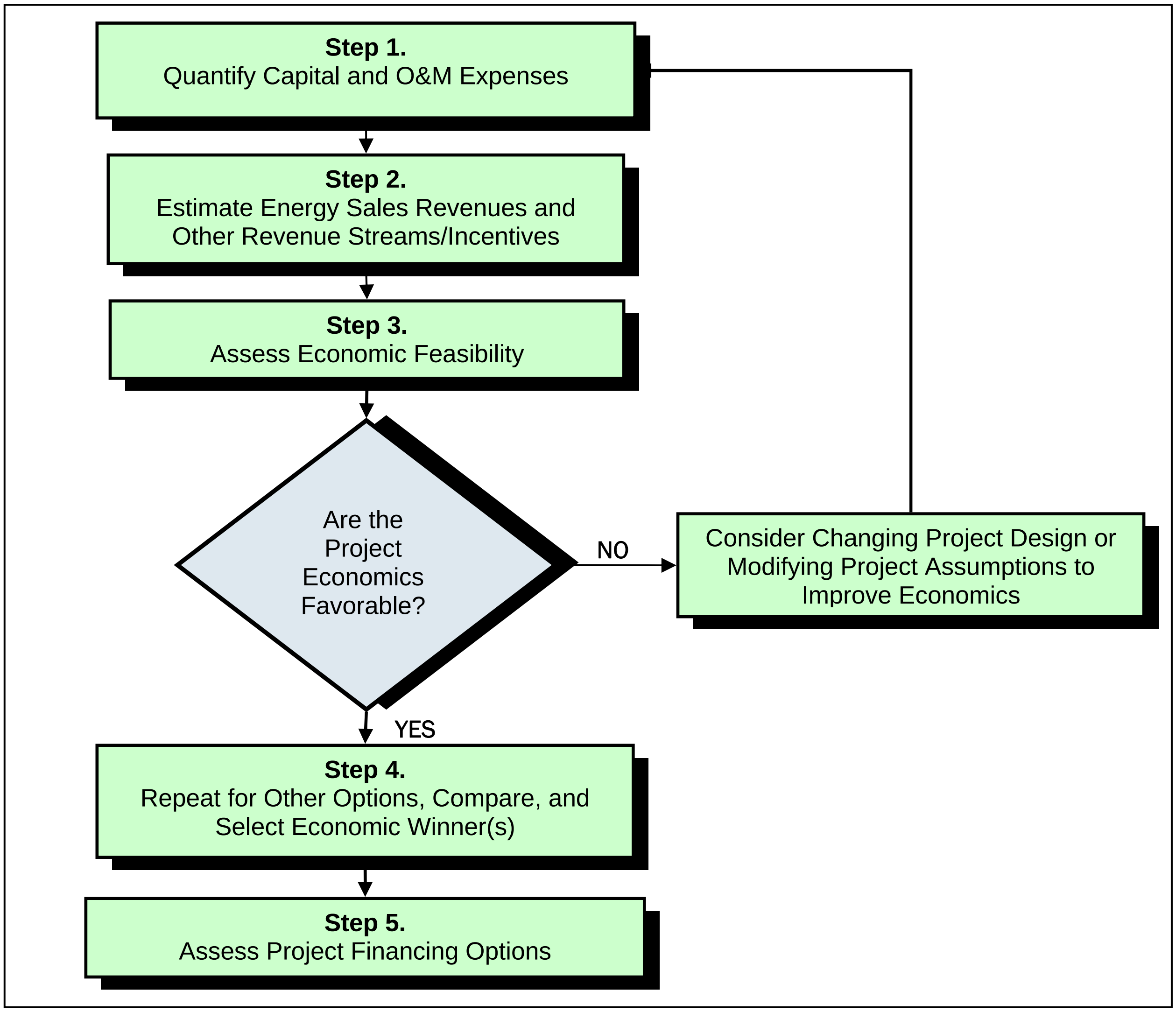
If the preliminary economic assessment shows that a project may be well-suited to the landfill, then a detailed economic assessment tailored to the landfill and potential project options should be performed. This feasibility assessment will often require the assistance of a qualified LFG professional engineering consultant or project developer. The detailed economic assessment is an essential step before preparing a system design, entering into contracts, or purchasing materials and equipment for the project.

The steps taken in both the preliminary and detailed economic feasibility assessments are similar, but the site-specific detail is different. For example, a preliminary feasibility study is based on *typical* costs (e.g., typical equipment costs, typical right-of-way and permitting costs, typical financing methods and interest rates). A detailed feasibility study, on the other hand, is based on *project-specific* costs and estimates (e.g., cost quotes for a specific model of equipment appropriate to the landfill, assessment of right-of-way costs depending on pipeline routes and number of land owners, assessment of permitting costs depending on state-specific permitting requirements, specific financing methods and interest rates). In both cases, the outputs of these assessments include costs and measures of financial performance required to make investment decisions, such as:

- Total installed capital costs
- Annual costs in first year of operation
- Internal rate of return (IRR)
- Payback period
- Net present value (NPV)

The economic assessment process typically includes five steps, as shown in Figure 4-1. The following sections discuss these five steps and provide helpful links, examples, and resources to aid in the evaluation process.

Figure 4-1. The Economic Evaluation Process



4.1 Step 1: Quantify Capital and O&M Costs

LFG energy project costs may include costs for gas collection and flaring, electricity generation, direct use, or other project options. Generally speaking, each LFG energy project will involve the purchase and installation of equipment (capital costs) and the expense of operating and maintaining the project (O&M costs). Cost elements common to various LFG energy projects are listed below, and the following sections describe in more detail specific factors that may influence the project costs and typical cost ranges for the more common project types.

Capital (i.e., equipment) costs include:

- Design and engineering and administration
- Permits and fees
- Site preparation and installation of utilities
- Equipment, equipment housing, and installation
- Startup costs and working capital

O&M cost elements include:

- Parts and materials
- Labor
- Utilities
- Financing costs
- Taxes
- Administration

Gas Collection System and Flaring Costs

One necessary component of an LFG energy project is the gas collection and flare system. This equipment gathers the LFG for combustion in the project's flare, electricity-generating equipment, or direct-use device, and provides a way to combust the gas when the project is not being operated. The collection system and flaring costs should be included as project costs only if these systems do not currently exist at the landfill. If a gas collection and flare system exists, it represents a "sunk" cost and the project costs need only include modifications to the system to tie in project equipment.

The typical LFG collection and flare system is approximately $18,000 per acre for installed capital costs, with annual O&M costs of around $4,000 per acre.[1] These costs can vary depending on several design variables of the gas collection system. The gas collection and flare system components and key factors that influence the costs of these components are listed below:

[1] Singleton, A., Eastern Research Group. 2007. *Landfill Gas Energy and Financing Options in North Carolina and the U.S.* Prepared for U.S. EPA Landfill Methane Outreach Program (LMOP) and presented to Cherokee Financial.

- Gas collection wells or collectors (key factors: area and depth of waste, spacing of wells or collectors).
- Gas piping (key factors: gas volume, length of piping required).
- Condensate knockout drum (key factor: volume of drum required).
- Blower (key factor: size required).
- Flare (key factors: flare type — enclosed or open, ground or elevated — and size).
- Instrumentation and control system.

It is important to decide early on whether to collect gas from the entire landfill or just the most productive area. Note that this decision may be dictated in some cases by regulatory requirements to collect gas. It is often most cost-effective to put in a smaller collection system first and then extend the system over time as new areas are filled and begin to produce significant quantities of gas. This approach has the added benefit of creating multiple systems that run in parallel, thereby allowing the project to continue operating at reduced capacity when a piece of equipment (e.g., a blower) is temporarily out of service.

Electricity Project Costs

The most common technology options available for developing an electricity project are internal combustion engines, gas turbines, microturbines, and small engines. Each of these technologies is generally better suited to certain project size ranges, as shown in Table 4-1. For example, small internal combustion engines and microturbines are generally best suited for small or unique power needs. Standard internal combustion engines are well-suited for small- to mid-size projects, whereas gas turbines are best suited for larger projects. A few boiler/steam turbine systems are also in operation at very large landfills (e.g., for 30–50 megawatt [MW] projects). Furthermore, if there is a use for the heat produced from the combustion of the LFG in the electricity-generating equipment, then a combined heat and power (CHP) project may be a preferable option. CHP systems are discussed in the "Other Project Options" section of this chapter.

Because project LFG flow changes over the life of the project, it is important to decide whether to size equipment for minimum flow, maximum flow, or average flow. This may help determine which technology is best suited for the project. Due to the high capital cost of electricity generating equipment, it is often advantageous to size the project at (or near) the minimum gas flow expected during the 15-year project life. This approach, however, can result in lost opportunity to generate electricity and receive revenues in years when gas is more plentiful. The best sizing approach for the project will largely be influenced by the site-specific gas curve, electricity rate structures, other revenue streams, and contract obligations (i.e., minimum electricity generation requirements). It may be worth evaluating the economics of sizing near the minimum and near the maximum gas flow. Also consider adding generating capacity (more internal combustion engines or gas turbines) over time as flow from the landfill increases.

For a basic electricity project, the costs associated with the project involve purchasing, installing, and operating/maintaining several components:

- Gas compression and treatment to condition LFG for use in the internal combustion engine or turbine.
- Internal combustion engine/gas turbine and generator set to generate the electricity.
- Interconnect equipment which is necessary for adding electricity to the grid.

For further discussion of LFG treatment and electricity project technologies, see Chapter 3.

As a guide to start a preliminary assessment, Table 4-1 lists some typical costs and applicable LFG energy project sizes for the most common electricity generation technologies. These costs include costs for the electricity generation equipment as well as costs for typical compression and treatment systems appropriate to the particular technology and interconnection equipment. Treatment costs, however, can vary widely depending on whether siloxane removal or other treatment is required. Interconnection costs can vary depending on project size and utility policies and requirements. For further information on interconnection, see the EPA CHP Partnership's Interconnection Web page.

Table 4-1. LFG Electricity Project Technologies — Cost Summary

Technology	Optimal Project Size Range	Typical Capital Costs ($/kW)*	Typical Annual O&M Costs ($/kW)*
Microturbine	1 MW or less	$5,400	$350
Small internal combustion engine	1 MW or less	$1,700	$180
Large internal combustion engine	800 kW or greater	$1,300	$160
Gas turbine	3 MW or greater	$970	$110

* 2007 dollars.
kW: kilowatt
MW: megawatt

Example preliminary economic assessments for a 3 MW internal combustion engine electricity project are presented in Appendix 4-A. These case studies can provide an idea of typical inputs, assumptions, and outputs expected from a preliminary economic assessment. LMOP provides assistance in performing preliminary economic assessments of these technologies with its LFGcost-Web tool available to LMOP Partners. Before moving forward, however, a more detailed site-specific analysis will be needed.

Direct-Use Project Costs

A direct-use project may be a viable option if an end user is located within a reasonable distance of the landfill. Examples of direct-use projects include industrial boilers, process heaters, kilns, furnaces; or space heating for commercial, industrial, or institutional facilities or for greenhouses.

For direct-use projects, costs may vary depending on the end user's requirements, but will typically involve the following items:

- Gas compression and treatment to condition gas for the end user's equipment
- A gas pipeline to transport LFG to the end user
- A condensate management system for removing condensate along the pipeline

The size of the pipeline can affect project costs. For projects with increasing gas flow over time, it is often most cost-effective to size the pipe at or near the full gas flow expected during the life of the project and to add compression and treatment equipment as gas flow increases.

Table 4-2 lists typical cost ranges for the components of a direct-use project. The costs shown below for the gas compression and treatment system include compression, moisture removal, and filtration equipment typically required to prepare the gas for transport through the pipeline and for use in a boiler or process heater. If more extensive treatment is required to remove other impurities, costs will be higher. The gas pipeline costs also assume typical construction conditions and pipeline design. Pipelines can range from less than a mile to over 20 miles long, and length will have a major effect on costs. In addition, the costs of direct-use pipelines are often affected by obstacles along the route, such as highway, railroad, or water crossings.

Table 4-2. LFG Direct-Use Project Components — Cost Summary

Component	Typical Capital Costs*	Typical Annual O&M Costs*
Gas compression and treatment	$260/scfm	$111/scfm
Gas pipeline and condensate management system	$53/foot	Negligible

* 2007 dollars.
scfm: standard cubic feet per minute

End users will likely need to modify their equipment to make it suitable for combusting LFG, but these costs are usually borne by the end user and are site-specific to their combustion device. Landfill owners or LFG energy project developers may need to inform the end user that they are responsible for paying for these modifications, noting that modification costs are normally minimal and the savings typically achieved by using LFG will more than make up for any equipment modification expenses. LMOP has developed a boiler retrofit fact sheet to help potential end users understand what types of modifications may be needed to use LFG in a boiler. The fact sheet also provides several examples of where LFG has been used in boiler fuel applications. Additional case studies for LFG uses at industrial and commercial sites are also available.

Example preliminary economic assessments for a typical direct-use project (in this case, 1,160 cubic feet per minute [cfm] LFG) with either a 5- and 10-mile pipeline are presented in Appendix 4-B. These case studies can provide ideas about typical inputs, assumptions, and outputs expected from a preliminary economic assessment.

Other Project Options

In addition to electricity and direct-use projects, other less common LFG energy project options exist, including CHP, leachate evaporation, vehicle fuel, and upgrading to high-Btu gas for sale to natural gas companies. These technologies are not as universally applicable as the more traditional LFG energy projects, but given the right situation, they can be very cost-effective and may be worth exploring as potential project options.

CHP involves capture and use of the waste heat produced by electricity generation. These projects are gaining momentum, as they provide maximum thermal efficiency from the collected LFG. Since the steam or hot water produced by a CHP project is not economically transported long distances, CHP is a better option for end users located near the landfill, or for projects where the LFG is transported to the end user's site and both the electricity and the waste heat is generated at their site. The electricity produced by the end user can be used on site or sold to the grid. EPA's CHP Partnership provides additional discussion on various CHP technology options available to LFG and other biomass projects.

Leachate Evaporators combust LFG to evaporate most of the moisture from landfill leachate, thus greatly reducing the leachate volume and subsequent disposal cost. These projects are cost-effective in situations where leachate disposal in a publicly owned treatment works or wastewater treatment plant is unavailable or very expensive.

Vehicle Fuel Applications involve the production of compressed natural gas (CNG), liquefied natural gas (LNG), or methanol. This process involves removing methane and other trace impurities from LFG to produce a high-grade fuel that is approximately 95 percent methane or greater. Currently, CNG and LNG vehicles make up a very small portion of motor vehicles in the United States, so there is not a large demand for these vehicle fuels. With interest in alternative fuels continuing to grow, demand is expected to increase. Furthermore, landfill owners/operators can achieve cost savings if these fuels can be used for the landfill's truck fleets. Costs associated with this option include converting the vehicles to use the alternate fuel and installing a fueling station.

To Upgrade LFG to Produce High-Btu Gas, a variety of technologies, described in Chapter 3, can be used to separate the methane and carbon dioxide components of LFG to provide methane for sale to natural gas suppliers or for use in applications requiring a high-Btu fuel. Although expensive, increasing energy costs may make high-Btu gas a more viable option. These projects are ideally suited for large landfills located near natural gas pipelines.

CHP and leachate evaporation project assessments are included as options in LFGcost-Web (for Partners). LMOP can assist with preliminary economic analyses for these technologies.

4.2 Step 2: Estimate Energy Sales Revenues and Other Revenue Streams or Incentives

Electricity Project Revenues

The primary revenue component of the typical electricity project is the sale of electricity to the local utility. This revenue stream is affected by the electricity buy-back rates (i.e., the rate at which local utility purchases electricity generated by the LFG energy project). Electricity buy-back rates for new projects depend on several factors specific to the local electric utility and the type of contract available to the project, but typically range between 4 and 11 cents per kilowatt-hour (kWh).[2, 3, 4] The upper end of this range represents premium pricing for renewable electricity. Occasionally, the electricity is sold to a third party at a rate that is attractive when compared to the local retail electricity rates. When assessing the economics of an electricity project, it is also important to consider the avoided cost of the electricity used on site. Electricity generated by the project that is used in other operations at the landfill is, in effect, electricity that the landfill does not have to purchase from a utility. This electricity is not valued at the buy-back rate, but at the rate the landfill is charged to purchase electricity (i.e., retail rate). The retail rate is often significantly higher than the buy-back rate.

LFG energy projects can potentially use a variety of additional environmental revenue streams, which typically take advantage of the fact that LFG is recognized as a renewable, or "green," energy resource. These additional revenues can come from premium pricing, tax credits, greenhouse gas credit trading, or incentive payments. They can be reflected in an economic analysis in various ways, but typically, converting to a cents/kWh format is most useful. LFGcost accommodates four common types of electric project credits: a direct cash grant, a renewable energy tax credit expressed in dollars per kWh, a direct greenhouse gas (carbon) credit expressed in dollars per metric ton of carbon dioxide equivalent, and a direct electricity tax credit expressed in dollars per kWh. The following list includes the available environmental revenue streams that an LFG energy project could possibly use.

- Premium pricing is often available for renewable electricity (including LFG) that is included in a green power program, through a Renewable Portfolio Standard (RPS), a Renewable Portfolio Goal (RPG), or a voluntary utility green pricing program. These programs could provide additional revenue above the standard buy-back rate because LFG electricity is generated from a renewable resource. The LMOP online funding guide features a list of states with RPS or RPG that include LFG energy. The National Renewable Energy Laboratory provides green power pricing lists that show utilities and power providers that are using LFG and in which states these products are available.

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[2] U.S. EPA Landfill Methane Outreach Program. 2007. *An Overview of Landfill Gas Energy in the United States.*

[3] Michels, M. 2008. Telephone call between M. Michels, Cornerstone Engineering, and C. Burklin, ERG. (June 15, 2008). Re: Typical prices for sale of electricity and LFG from LFG energy projects.

[4] U.S. DOE Energy Information Administration. 2008. Average Wholesale Price Table. http://www.eia.doe.gov/cneaf/electricity/wholesale/wholesale.html and http://www.eia.doe.gov/cneaf/electricity/wholesale/wholesalet2.xls

- Renewable energy certificates (RECs) are sold through voluntary markets to consumers seeking to reduce their environmental footprint. They are typically offered in 1 megawatt-hour (MWh) units, and are sold by electricity generators using LFG to industries, commercial businesses, institutions, and even private citizens who wish to achieve a corporate renewable energy portfolio goal or to encourage renewable energy. If the electricity produced by an LFG energy project is not being sold as part of a utility green power program or green pricing program, the project owner may be able to sell RECs through voluntary markets to generate additional revenue. Note that there are certification programs for RECs to be sure the amount of electricity generated can be verified and renewable attributes of electricity are not sold twice. EPA's Green Power Partnership provides a state-by-state directory of green power providers in its Green Power locator.

- Tax credits, tax exemptions, and other tax incentives, as well as federal and state grants, low-cost bonds, and loan programs are available to potentially provide funding for an LFG energy project. For example, Section 45 of the Internal Revenue Code provides a per-kWh federal production tax credit for electricity generated at privately owned LFG electricity projects. To qualify for the credit, which was 1.0 cent per kWh for the 2007 taxable year, all electricity produced must be sold to an unrelated person during the taxable year. Under legislation passed in October 2008, the placed-in-service date deadline for LFG energy projects to be eligible for the first 10 years of production is December 31, 2010. Another popular funding option is the Clean Renewable Energy Bond (CREB) program, which allows electric cooperatives, government entities, and public power producers to issue bonds to finance renewable energy projects including LFG electricity projects. The borrower pays back only the principal of the CREB, and the bondholder receives federal tax credits in lieu of the traditional bond interest. More details about these incentives can be found in LMOP's online funding guide. This document is updated quarterly with the latest information on a wide range of available tax credits and incentive programs applicable to LFG energy projects.

- Many state and regional government entities are establishing their own greenhouse gas initiatives to cap or minimize greenhouse gas emissions within their jurisdictions. Examples include the Regional Greenhouse Gas Initiative (RGGI), the Washington carbon dioxide offset program, and the Massachusetts carbon dioxide reduction from new plants. Some of these programs establish a cap-and-trade program on carbon dioxide emissions, while others require new fossil-fueled boilers and power plants to either implement or contribute to funding of offset projects, such as LFG energy. Programs may have certain size restrictions or qualification requirements, so it is necessary to ask the state government whether it participates in such a program and what the requirements may be. See the EPA document "Environmental Revenue Streams for CHP and Biomass Projects" for additional information.

- Certain LFG energy projects may qualify for participation in nitrogen oxides cap-and-trade programs, such as the nitrogen oxides State Implementation Plan (SIP) call. The revenues for these incentives vary by state and will depend on factors such as the allowances allocated to each project, the price of allowances on the market, and if the project is a CHP project (typically CHP projects receive more revenue due to credit for avoided boiler fuel use). In the past, prices have ranged from $500 to $7,000 per ton of nitrogen oxides,[5] with the 2007 prices being near $1,000/ton.[6] See the EPA document "Environmental Revenue Streams for CHP and Biomass Projects" for additional information.

[5] U.S. EPA and Ozone Transport Commission. 2003. *OTC NO_x Budget Program — 1999–2002 Progress Report.* http://www.epa.gov/airmarkets/progress/docs/otcreport.pdf

[6] Argus Air Daily. April 19, 2007. Volume 14.

- LFG energy projects are also well suited to voluntary emissions trading programs. The Chicago Climate Exchange (CCX) offers a credit of 18.25 metric tons of carbon dioxide per metric ton of methane combusted. In the past, prices offered have ranged from $1 to $7 per metric ton of carbon dioxide equivalent. The credit includes certain restrictions based on project start dates; also, if the landfill is required by law to collect and combust LFG, then it cannot receive credit for methane reductions. In addition to methane reduction offsets, LFG energy projects that produce electricity may also qualify for CCX emission offsets for renewable energy as long as the RECs are not being sold elsewhere. To learn more about the CCX program and to find out if a project might be eligible, see the CCX Web site.

- Bilateral trading and greenhouse gas credit sales are other voluntary sources of revenue. Unlike the CCX, bilateral trades are project-specific and are negotiated directly between a buyer and seller of greenhouse gas credits. In these cases, corporate entities or public institutions, such as universities, may wish to reduce their “carbon footprint” or meet internal sustainability goals, but do not have direct access to developing their own project. Therefore, a buyer may help finance a specific project in exchange for the credit of offsetting greenhouse gas emissions from their organization. These may be simple transactions between a single buyer and seller (e.g., the project developer), or may involve brokers that “aggregate” credits from several small projects for sale to large buyers.[7] Similar to certification programs for RECs, voluntary and bilateral trading programs often involve certification and quantification of greenhouse gas reductions to ensure validity of the trade. As a result, there can be rigorous monitoring and recordkeeping requirements for participating in the program. The additional revenue, however, is likely to justify these additional efforts.

Direct-Use Project Revenues

The primary source of revenue for direct-use projects is the sale of LFG to the end user; the price of LFG, therefore, dictates the projects’ revenues. Typical LFG prices are around $8.00 per million British thermal units (MMBtu)[8] or 0.75¢ per megajoule and may be indexed to the price of natural gas (e.g., 70 percent of natural gas prices). Prices will vary depending on site-specific negotiations, the type of contract, and other factors. (Chapter 5 contains additional information about factors that can affect LFG pricing.) In general, the price paid by the end user must provide an energy cost savings that outweighs the cost of required modifications to boilers, process heaters, kilns, and furnaces in order to burn LFG. The LMOP LFG boiler retrofit fact sheet illustrates the modifications potentially needed to burn LFG and presents several examples of effective direct-use projects.

Federal and state tax incentives, loans, and grants are available that may provide additional revenue for direct-use projects. The LMOP online funding guide presents updated information on available incentives and how to qualify for them. Greenhouse gas emissions trading programs, such as the CCX, are also potential revenue streams for direct-use projects.

LMOP’s online support software, LFGcost-Web, accommodates three common types of direct LFG use credits: a direct cash grant, a renewable energy tax credit expressed in $/MMBtu, and a direct

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[7] SCS Engineers. 2007. *Carbon Credits Bilateral Markets a.k.a. Voluntary Offset or Over-the-Counter Markets.* Presented at the PWIA Fall Conference, September 6, 2007.

[8] Michels, M. 2008. Telephone call between M. Michels, Cornerstone Engineering, and C. Burklin, ERG. (June 15, 2008). Re: Typical prices for sale of electricity and LFG from LFG energy projects.

greenhouse gas reduction credit expressed in $/metric ton of carbon dioxide equivalent. Note that the renewable energy tax credit is available only to private entities that pay taxes.

Lancaster County Solid Waste Management Authority (LCSWMA) — Selling Emission Offsets on the Chicago Climate Exchange[9]

In 2005, LCSWMA and PPL Energy Services formed a partnership to develop a project that extracts methane from the Creswell and Frey Farms Landfills to generate both electricity and steam (CHP). LCSWMA voluntarily installed the gas collection wells and pipeline. PPL owns the energy generation plant that is located next to Turkey Hill Dairy. PPL buys LFG from LCSWMA. They use two internal combustion engines to generate electricity to sell into the regional grid. The waste heat from the internal combustion engines is used to produce steam, which is sold to the dairy, providing 80 percent of the dairy's steam needs and reducing the dairy's fuel costs.

LCSWMA realizes significant revenues from the sale of greenhouse gas offsets. They were the first public environmental services authority to join and sell carbon dioxide emission offset credits generated from LFG on CCX. LCSWMA meets CCX offset project criteria because they own the LFG recovery system, installed it voluntarily after the specified date, and have ownership of the carbon dioxide emission offsets.

LCSWMA expects to sell up to 80,000 metric tons of carbon dioxide equivalent per year, and anticipates up to $300,000 per year in revenue. Prices in late 2006 were near $4/metric ton. The revenue from these sales is helping LCSWMA rapidly pay back its gas collection system installation costs.

4.3 Step 3: Assess Economic Feasibility

Once the costs and revenues for a project have been determined and if the project is still considered viable, an economic feasibility analysis should be performed. LMOP Partners can use LFGcost-Web to perform the preliminary economic feasibility. When performing a more detailed analysis, however, many LFG energy consulting companies and LFG energy project developers rely on their own financial pro forma programs, which may enable a more detailed analysis for a specific project. This financial pro forma is a spreadsheet model to estimate cash flow based on the costs and revenue streams, and it provides a more accurate estimate of the probable economic performance over the lifetime of the project. To perform this analysis, calculate and compare the expenses and revenue on a year-by-year basis for the life of the project. Several elements must be input into the model, most of which can be obtained from LFGcost (or a more detailed site-specific cost analysis) and an analysis of the revenue streams:

- Project capital and O&M cost data.
- Operation summary — electricity generated, Btu delivered, gas consumed.
- Financing costs — the amount of the project that is financed and the interest rate will determine how much it will cost to service the project's debt each year.
- Inflation rates — this could impact O&M costs, especially if the product is sold at a fixed price over a term.

[9] Lancaster County Solid Waste Management Authority. 2007. *Selling Landfill Gas Emission Offsets on the Chicago Climate Exchange.* Presented at the 2007 LMOP Conference, Baltimore, Maryland, January 23, 2007.

- Product price escalation rates — increases or decreases in the price of electricity or LFG will affect project revenues.

- Revenue calculation — sales of electricity and incentive/markets revenue.

- Cost uncertainty factors — the project capital or O&M costs may be less or more than expected in any given year.

- Tax considerations — taxes or tax credits that may apply will affect revenue streams.

The financing mechanisms used for a project will affect the cost to generate electricity or provide LFG to the direct user. Factors such as project lifetime, loan periods, interest rates, taxes, discount rates, and down payment percentage all affect project cost and therefore the cost of generating the electricity or providing the LFG to the direct user. These costs account for the funds required to purchase and install the capital equipment (capital amortization costs) and, together with the O&M costs, constitute a more representative cost of producing electricity or providing LFG to a direct user. Project lifetime and loan periods indicate how long a project will be active, compared to the length of the payment period for the project. Interest rates and down payment percentage affect how much is needed to pay the lender (if a loan is used to pay for the project). The discount rate affects how much a bond must yield when due (if municipal bonds are issued to fund the project). Taxes will affect how much revenue is left to pay off the equity and provide the expected return (i.e., post-tax revenue). Depending on the developer's contract with the landfill, royalty costs may also apply if the developer does not own the gas.

A pro forma analysis will present the results of calculating measures of economic performance that are used to determine financial feasibility, such as:

- *Internal rate of return (IRR*) — Return on investment based on the total revenue from the project and construction grants, minus down payment. This is the project cash flow, and expresses a percent "yield" on investment in the project.

- *Net present value (NPV) at year of construction* — The value of the project at the first year that is equivalent to all the cash flows, based on the discount rate. This is how much money the project will cost over its lifetime, considering that the money could have been invested elsewhere and accrued interest.

- *NPV payback period* — This is the length of time (in years) required for the project to pay for itself. The shorter the time, the better.

- *Annual cash flow —* Total revenue from the project minus expenses, including O&M and capital amortization costs. Essentially the income the project generates in a year.

For a preliminary assessment, LFGcost will calculate several of these financial performance indicators, such as IRR, NPV, and NPV payback period. It will also provide a preliminary capital and O&M cost estimate for the project.

Table 4-3 summarizes results of the 3 MW internal combustion engine and direct-use case studies as an example of a preliminary analysis of economic feasibility. These cases assume the landfill does not have a gas collection and flaring system. While a municipal project may be more common, the private case illustrates a situation for a privately owned landfill, or where a private developer will develop a project at a municipal landfill. More variations and options for these case studies, as well as descriptions of the cases, are presented in Appendix 4-A (electricity projects) and Appendix 4-B (direct-use projects).

Table 4-3. Example Financial Performance Indicators for Projects Requiring a Collection and Flare System

Economic Performance Parameter	3 MW Engine Project (With Collection and Flaring System Costs)*		Direct-Use Project (5 Mile — With Collection and Flaring System Costs)*	
	Private**	Municipal†	Private**	Municipal†
Net present value‡	($1,721,074)	($952,589)	$5,104,484	$11,572,917
Internal rate of return	-2%	1%	82%	131%
Net present value payback (years)	None	None	2	1
Capital costs‡	$5,178,761	$5,178,761	$2,915,398	$2,915,398
O&M costs‡	$826,671	$826,671	$411,516	$411,516

* For the 3 MW internal combustion engines, the electricity sale price is 6¢/kWh; for direct-use projects, the LFG price is $8/MMBtu.

** 20% down payment, 8% interest rate. See case named “Electricity 2” in Appendix 4-A for the internal combustion engine project and “Direct Use 2” in Appendix 4-B for the direct-use project.

† 20% down payment, 80% municipal bond, 6% discount rate. See case named “Electricity 9” in Appendix 4-A for the internal combustion engine project and “Direct Use 8” in Appendix 4-B for the direct-use project.

‡ 2009 dollars.

Based on these results, the direct-use project is an attractive option and may be worth further consideration. The engine project, however, is not viable based solely on typical revenues from electricity sales. In this case, though, the project may qualify for various greenhouse gas credit programs, as it involves the installation of a new methane collection system and the subsequent destruction of that methane. If the collection system was installed voluntarily and meets other criteria, the additional revenues available from greenhouse gas credits may significantly improve the economic prospects of this project.

For illustration, applying a $4/metric ton carbon dioxide equivalent credit to this project would yield an additional $564,000 per year on average, which would result in $9,241,200 in additional revenue over the 15-year life of the project. This credit brings the IRR for the private 3 MW internal combustion engine project up to 21 percent from a negative value. Therefore, considering the available incentives, credits, or market revenues that a project may qualify for will be an important part of an economic analysis. See the case study named “Electricity 4” in Appendix 4-A for details on the financial results of this scenario.

Alternatively, the project might be able to take advantage of green pricing or other incentive programs. For example, if the electricity sales revenue could be increased to 7.5¢/kWh instead of 6¢/kWh (e.g., through a green power program or sale of RECs), then the IRR for the private case would increase to 10 percent. See the case study named “Electricity 3” in Appendix 4-A for more details on the financial results of this scenario.

LFG energy projects where a gas collection and flaring system is already in place realize improved economics because there are no collection system installation costs. However, such projects will likely not be eligible for credits for greenhouse gas capture. Table 4-4 summarizes cases where a LFG collection and flaring system is in place.

Table 4-4. Example Financial Performance Indicators for Projects With a Collection and Flare System in Place

Economic Performance Parameter	3 MW Engine Project (Without Collection and Flaring System Costs)*		Direct-Use Project (5 Mile — Without Collection and Flaring System Costs)*	
	Private**	Municipal†	Private**	Municipal†
Net present value‡	$1,440,474	$4,429,452	$7,362,931	$15,724,112
Internal rate of return	25%	40%	191%	304%
Net present value payback (years)	7	4	1	1
Capital costs‡	$3,555,156	$3,555,156	$1,683,253	$1,683,253
O&M costs‡	$470,328	$470,328	$134,456	$134,456

* For the 3 MW engines, the electricity sale price is 6¢/kWh; for direct-use, the LFG price is $8/MMBtu.

** 20% down payment, 8% interest rate. See case named “Electricity 1” in Appendix 4-A for the engine project and “Direct Use 1” in Appendix 4-B for the direct-use project.

† 20% down payment, 80% municipal bond, 6% discount rate. See case “Electricity 7” in Appendix 4-A for the engine project and “Direct Use 6” in Appendix 4-B for the direct-use project.

‡ 2009 dollars.

Here again, the direct-use projects appear more favorable, but finding a suitable end user within a reasonable distance is not always possible. The fact that none of these projects has the burden of installing a collection and flaring system makes each option viable. That notwithstanding, if additional revenues are added, such as premium pricing on electricity, then the internal combustion engine case becomes considerably more advantageous. For example, if a 2¢/kWh credit on top of the buy-back rate is applied, the IRR for the private 3 MW internal combustion engine project becomes 47 percent, with a payback of 3 years. (See the case study named “Electricity 5” in Appendix 4-A for further details.) As noted earlier, one should consider all possible revenue streams when performing an economic evaluation.

Finally, it is important to bear the developer’s objectives in mind. Often, municipalities do not expect the same IRR and payback periods as private entities. Corporations, on the other hand, usually have competing uses for their limited capital and prefer to invest in projects with the greatest IRR and to recover their capital investment in just a couple of years. The financial requirements of the parties involved in developing a project must be considered in determining economic feasibility and selecting financing mechanisms. A project at a publicly owned landfill that is not financially attractive to a project developer could still be implemented through self-development or partnering arrangements. See Chapters 5 and 6 for more information on project structures and project development options, and Section 4.5 of this chapter for more information about financing mechanisms.

4.4 Step 4: Compare All Economically Feasible Options and Select Winner(s)

After multiple project options are compared, some options may emerge as clearly uncompetitive and not worth further consideration; alternatively, there may be one option that is clearly the superior choice and warrants a more detailed investigation. It is most likely, however, that multiple energy project options are available, and it may be necessary to compare the economic analyses of each option and select the most promising option, bearing in mind any non-price factors.

A head-to-head economic comparison can be used to rank the financial performance of each option to select a winner. This comparison should incorporate several economic measures in the ranking, since no single measure can guarantee a project's economic success. For example, projects could be ranked based on the NPV after taxes, making sure that the IRR requirements are satisfied, or that the debt incurred to finance the project is within reach. It may turn out that the project with the highest IRR may also have high capital and O&M costs and may simply cost too much for the financing budget. If so, a lower IRR project that costs less (and is easier to finance) could be the best option.

At this point, important non-price factors that may impact the project but may not be quantifiable by the economic analysis should be considered, such as risk related to attainment of emissions limits or risk associated with technology. For example, the project might be located in a severe non-attainment area where stringent emission limits are in place, making it difficult and expensive to get a permit for a new combustion device. In this case, finding a direct user that could supplant some of their current fuel use with LFG might be a more viable project. Likewise, some project options may be based on more proven technologies and would incur lower risk than other, newer technologies, despite their having the potential for a greater return on investment. The risk involved may influence the financing available and could require a higher-interest loan.

4.5 Step 5: Assess Project Financing Options

Many financing options are available to landfills and project developers, including finding equity investors, using project finance, and issuing municipal bonds. This section describes common types of financing and some potential advantages and disadvantages of each.

What Lenders/Investors Tend to Look For

Typically, lenders and project investors look at the expected financial performance of the project to decide whether or not to lend or invest in the LFG energy project. The debt coverage ratio is an important measure that the lender/investor will want to see (in addition to the IRR and other financial performance indicators from the pro forma analysis). The debt coverage ratio is the ratio of a project's annual operating income (project revenue minus O&M costs) to the project's annual debt repayment requirement. Lenders usually expect the dept coverage ratio to be at least 1.3 to 1.5 to demonstrate that the project will be able to adequately meet debt payments.

The higher the risk associated with a project, the higher the return expected by lenders or investors. Risks vary by site and by project and may entail various components of the overall project, from availability of LFG to community acceptance. In many cases, however, risks can be mitigated with a well-thought-out project, strong financial pro forma, use of proven equipment vendors and operators, and a well-structured contract. Table 4-5 lists the various categories of risk that might be associated with a landfill project, and potential measures that can be taken to mitigate these risks.

Table 4-5. Addressing LFG Energy Project Risks

Risk Category	Risk Mitigation Measure
LFG availability	• Measure LFG flow from existing system • Hire expert to report on gas availability • Model gas production over time • Execute gas delivery contract/penalties with landfill owner • Provide for backup fuel if necessary
Construction	• Execute fixed-price turnkey projects • Include monetary penalties for missing schedule • Establish project acceptance standards, warranties
Equipment performance	• Select proven technology for proposed energy use • Design LFG treatment system to remove impurities, as necessary • Get performance guarantees, warranties from vendor • Include major equipment vendor as partner • Select qualified operator
Environmental planning	• Obtain permits before financing (air, water, building) • Plan for condensate disposal
Community acceptance	• Obtain zoning approvals • Demonstrate community support
Power sales agreements (PSA)	• Have signed PSA with local utility • Match PSA pricing, escalation to project expenses • Include capacity, energy sales, and RECs in energy rate • Sufficient contract term to match debt repayment schedule • Confirm interconnection point, access, requirements • Include force majeure (act of God) provisions in PSA
Energy sales agreements (ESA)	• Signed ESA with energy customer • Fixed energy sales prices with escalation or market-based prices at sufficient levels to meet financial goals • Customer guarantees to purchase all energy delivered by project • Limit liability for interruptions, have backup
Financial performance	• Create financial pro forma • Calculate cash flows, debt coverage • Maintain working capital, reserve accounts • Budget for major equipment overhauls

Financing Approaches

Several possible approaches can be taken to financing the project, each of which is described briefly below. The approaches described here are not necessarily mutually exclusive; a mixture of different financing approaches may be available for a project and might be better suited to meeting specific financial goals. Contact financing consultants, developers, municipal/county staff who deal with bond financing, or LMOP Partners who developed similar LFG energy projects for additional information about financing approaches that have been successful in similar situations.

Private Equity Financing. This financing approach has been widely used in past LFG energy projects. It involves an investor who is willing to fund all or a portion of the project in return for a share of project ownership. Potential investors include some developers, equipment vendors, gas suppliers, industrial companies, and investment banks. For small projects without access to municipal bonds, private equity financing may be one of the few ways to obtain financing. Private equity financing has the advantages of lower transaction costs and usually the ability to move ahead faster than with other financing methods. However, this form of financing can be more expensive, and in addition to a portion of the cash flow, the investor might expect to receive benefits from providing finance, such as service contracts or equipment sales.

Project Finance. This is a popular method for financing private power projects. With this approach, lenders look to a project's projected revenues rather than the assets of the developer to ensure repayment. The developer, therefore, is able to retain ownership control of the project while still obtaining financing. Typically, the best sources for obtaining project financing are small investment capital companies, banks, law firms, or energy investment funds. The main disadvantages of project finance are high transaction costs and lender's high minimum investment threshold.

Municipal Bond Financing. In the case of municipally owned landfills and municipal end users, the local government might issue tax-preferred bonds to finance the LFG energy project. This approach is the most cost-effective way to finance a project, because the interest rate is often 1 or 2 percent below commercial debt interest rates, and can often be structured for long repayment periods. However, municipalities can face barriers to issuing bonds, such as private business use and securities limitations, public disclosure requirements, and high financial performance requirements. Check with the state or municipality in which the bond is issued to determine the terms for securing bond financing and the method for qualifying for the bond, and perhaps consult with a tax professional before deciding on whether tax-exempt or taxable bonds should be secured.

Direct Municipal Funding. This approach — possibly the lowest-cost financing available — uses the operating budget of the city, county, landfill authority, or other municipal government to fund the LFG energy project. It eliminates the need to obtain outside financing or project partners, and it avoids the delays caused from their project evaluation needs. Many municipalities, however, may not have sufficient budget to finance a project or may have many projects competing for scarce budget resources. Additionally, public approval may be required, which could add an additional layer of complication and potential delays.

Lease Financing. In this approach, the project owner/operator leases all or part of the LFG energy project assets. This arrangement usually allows the transfer of tax benefits or credits to an entity that can best make use of them. Lease arrangements can allow for the user to purchase the assets or extend the lease upon completion of the term of the lease. The benefit of lease financing is that it frees up capital funds of the owner/operator while allowing them control of the project. The disadvantages include complex accounting and liability issues, as well as loss of tax benefits to the project owner/operator.

Summary

LFG energy project development poses several risks and rewards. Landfill owners should keep detailed data records, be conservative on the energy potential from the landfill, carefully review pro forma statements, and assist the procurement process in any way possible; long delays from permits, public opposition, or financing can be a turn-off for investors. Project developers should allow for all parties to benefit from the project, conduct financial sensitivity analyses to accurately portray risks, and set conservative goals for project schedules, costs, and revenues. Successful project development requires that all parties work together to mitigate the project risks and ensure that they can survive with less-than-ideal project results.

5. Landfill Gas Contracts and Permitting

Chapter Overview

The purpose of this chapter is to provide an overview of the types of contracts needed to develop landfill gas (LFG) energy projects and the federal environmental regulations and permitting requirements that may affect LFG energy projects.

For landfill owner/operators, creating value from the sale of LFG, electricity generation, or environmental attributes through a contractual relationship with a buyer is one of the most critical elements to the success of an LFG energy project. This is particularly true if the project is intended to be financed. Entities providing the financing will be particularly interested in the terms and conditions of the agreement to transact the energy and environmental assets associated with the LFG energy project. The structure and potential risks in such contracts will have a direct impact on the terms offered by the financing entity. Therefore, both the landfill owner/operator and the project developer should thoroughly evaluate the elements of all contractual agreements, which represent an important step in the project development process.

This chapter provides guidance and considerations for landfill owner/operators and LFG energy project developers in securing contracts related to beneficial use and emission reduction projects. These contracts can be separated into three broad categories discussed in Sections 5.1 through 5.3:

- Power sales agreements (electrical generation projects)
- LFG purchase agreements (any beneficial use project type)
- Environmental attribute agreements (any project type)

Section 5.4 provides information for landfill owners and project developers about federal air quality, solid waste, and water quality regulations and permitting requirements that can pertain to LFG energy projects. The federal requirements are presented in general terms, as site-specific analyses are needed to determine which rules and permitting requirements apply to a particular LFG energy project, and each state has its own requirements for carrying out the rules and permitting programs.

5.1 Power Sales Agreements

Traditionally, electricity generated from an LFG energy project has been sold to investor-owned utilities (IOUs) that provide electrical service in the region where the project is located through a power purchase agreement (PPA). However, with the restructuring of the U.S. electricity sector in the late 1990s, non-regulated entities (e.g., independent power producers, co-operatives, municipalities, power marketers, and power purchasers) were given greater access to the electricity grid, which led to the creation of competitive electricity markets in many states and regions. With the advent of these markets, electricity can now be sold as a commodity, offering many more sales options to the power project developer/owner.

Landfill owners and project developers need to consider these sales carefully. The LFG energy project owner can now sell electricity and other attributes, including capacity, renewable attributes of the power, and ancillary services, as a "bundled" product, or sell them individually. Furthermore, the project owner can sell many of these electrical elements on either a daily basis or for a fixed term. Most LFG energy projects are "must run," meaning that they run all the time and are not dispatched by a system operator to meet variation in demand and electricity market price. Operators of dispatchable LFG electricity projects monitor market price and can bring the units on and off line to respond to electrical market prices; these projects are typically managed from a central location via remote connection to the facility's supervisory control and data acquisition (SCADA) systems. Dispatchable units give a project more flexibility to take advantage of price variations in the spot electrical markets.

Power Purchase Agreement With an IOU

Historically, the most common structure has been to sell the electricity to an IOU, cooperative, or municipal entity through a PPA. The electricity, including energy and capacity, is sold to the IOU at a fixed price with some kind of escalation or indexed price based on an estimate of short run avoided cost or some publicly available local market price mechanism. Environmental attributes related to electrical generation via LFG may or may not be included in the PPA. The sale of power alone, without environmental attributes, is known as "brown power," whereas the environmental attributes attributed to the generation of renewable energy are known as "green power." Executed PPAs might only address the transaction of brown power or might include some or all of the green power attributes. The green attributes related to electrical generation via LFG are discussed in greater detail in Section 5.3. These agreements are typically negotiated or obtained through a competitive bidding process. The terms of these contracts can vary greatly, from 1 to 15 years. Entities providing financing are most comfortable with traditional PPAs because of their predictable revenue stream. Financing entities prefer a PPA term equal to or longer than the term of the financing.

Power Sales Contract to a Power Marketer or Wholesale Buyer

LFG energy projects can sell their electricity to power marketers or wholesale buyers or to other market participants eligible to buy and/or sell electricity on these markets in states and regions with robust electricity markets where electricity pricing is transparent. Examples of such states/regions include the PJM Interconnection, the New York Independent System Operator, and the California Independent System Operator. The contract terms can vary widely, but below are two common forms:

- A fixed "bundled" rate that typically includes energy and capacity, and may include renewable attributes for power for a fixed term of 2 to 15 years. The rate can be adjusted annually for inflation.

- A variable rate for electricity (energy and/or capacity) at a premium or discount (depending on market conditions) to a publicly available market price for a fixed term. Rates may include a floor and/or ceiling price. Rates may adjust daily, monthly quarterly, bi-annually or annually. The term can be fixed for a period of 1 to 10 years.

Selling Directly Into a Market

Project developers/owners can sell directly into electricity markets for the market price for energy and capacity. The price for energy is usually determined theoretically a day ahead based on bids received, then updated in real time several times per hour (i.e., every 5 to 15 minutes) by the system operator. The market price is determined by the lowest marginal cost of the next generating unit to be dispatched and provide power to the system. Capacity is typically bid and prices determined for longer time periods — typically 1 to 6 months, but this varies. The renewable attributes of the power are not typically sold in these markets, but these markets may track and verify the production of these attributes.

Net Metering

In some states, net metering allows consumers, commercial, and industrial entities to offset their electrical use with appropriately sized renewable electric generation located on site. With net metering, the meter can run in either direction; customers are allowed to "bank" energy exported to the grid when their demand is low and import power from the grid when the generation is not operating or not able to fully meet their peak demand. States set their own net metering regulations and typically limit the capacity of the generation. Net metering is appropriate to consider:

- When the landfill or nearby business has an appropriately sized power load and meets the state net metering regulations.
- In regions with a high retail electric rate.
- Where grid interconnection costs make traditional grid-connected electric generation projects infeasible.

More information about net metering is available on the U.S. Department of Energy's Energy Efficiency and Renewable Energy Web site.

Other Consideration — Electric Grid Interconnection

In addition to contracting issues, LFG developers/owners must carefully consider the complexity, cost, and timing of interconnecting to the electric grid. Grid interconnection can be the most important issue in determining the feasibility of a project. Some factors that drive interconnection costs and timing include:

- Amount of megawatts (MW) the developer wants to connect to the grid.
- Size and capacity of surrounding distribution (12–15 kilovolt [kV]) and medium tension (20–69 kV) distribution lines.
- Location of the distribution substation.
- Interconnection procedures and regulations.
- Utility requirements (e.g., communications, protection, control).

These factors are highly dependent on the project's location and the utility's experience and willingness to interconnect with LFG energy and other distributed generation projects. In some regions and states, regional transmission operators (RTOs) and regulators are trying to make the interconnection process for small renewable projects more streamlined, transparent, and cost-effective. Early on in the project development cycle, the utility completes an interconnection feasibility study (paid for by the developer), which will define many of these issues. Project costs and timing can vary substantially among projects, so LFG energy developers should begin the interconnection process as early as possible and engage interconnection experts with experience in the state or region. An interconnect agreement will be required with the utility, as well as agreements for the design and construction of the interconnection.

5.2 LFG Purchase Agreements

A landfill owner/operator typically sells its electricity to a project developer or LFG end user for one of three purposes:

- For use as a substitute for other fuels (e.g., to fire boilers, kilns, furnaces) to create hot air, hot water, or steam. This is typically referred to as a direct-use project or as a medium–British thermal unit (Btu) project.
- To power an LFG-fired electricity generation facility.
- For injection into a natural gas distribution or transmission pipeline, after purification to natural gas pipeline standards (typically referred to as a high-Btu project).

Direct-Use Sales of Medium-Btu LFG

The three basic types of contracts for direct-use projects are fixed price, indexed price (where the cost of LFG is based on a discount of a posted natural gas price and will change over time), and a fixed/indexed hybrid approach. These contracts are usually set on a Btu delivered basis. The landfill owner/operator typically sells the delivered LFG at a discount to typical natural gas prices due to the following factors:

- The investment the developer and/or end user will need to make to transport and utilize the LFG (e.g., modification of existing equipment to burn LFG).
- Potentially higher operation and maintenance (O&M) costs due to the fact that LFG has more impurities than natural gas.
- The need for the end user to have backup fuels.

The level of discount is driven by the level of investment required to construct and operate the project and by how these costs are distributed among the participating parties.

Fixed Price Contracts. A guaranteed fixed price contract establishes a fixed price for the gas for a certain length of time. This price usually incorporates an escalator to account for inflation. The initial price for LFG is typically set at or below the average market price for natural gas and is based on costs to implement the LFG energy project and return on investment required by the participating parties. Because of the volatility of the natural gas pricing and its sharp increase in price in this decade, fixed price contracts for LFG are becoming less common.

Indexed Sales Contracts. Indexed LFG sales contracts typically offer a discount off a posted market price for natural gas (typically 20 to 50 percent below the average monthly cost of natural gas on the selected indices such as Henry Hub or NYMEX). This discount can vary significantly depending on how much investment is required and who is responsible for the investment. When negotiating price with the end user, the owner of the LFG should consider that the end user may not have access to the natural gas wholesale pipeline pricing indicated in most commonly available indices (e.g., Henry Hub). Buyers must pay additional costs for transportation, infrastructure construction, and distribution of the natural gas, which can run $0.75 to $2.00 per million Btu higher than these wholesale indices. Because of the volatility of natural gas prices, indexed LFG sales contracts are highly variable in terms of revenue; however, they do provide the end user with considerable savings and a lower risk profile by always being below the market price of natural gas. Additionally, indexed contracts typically include provisions for maximum and minimum pricing (e.g., ceiling and floor prices) to limit price risks on both sides of the contract agreement. Setting a floor price limit is essential to reducing the risk to the seller of the LFG, particularly if the seller is making a significant investment. A financing entity typically requires setting a floor price to ensure that debt payments can be made in all market conditions. A price ceiling is essential if the LFG buyer is making a significant investment; it also provides an additional incentive to use LFG. Typically, if one party is requiring a floor price, the counterparty asks for a ceiling price, or vice versa.

Hybrid Contracts. LFG sales contracts have also been implemented in other creative ways in order to minimize risk and maximize economic benefit. One such option is a hybrid of the two previous types of contract. In an example hybrid contract, a fixed price contract is implemented for a certain period of time (e.g., until the capital investment is recovered) and then converted into an indexed price contract. Sales costs depend on the level of investment and equity participants.

Guarantees. LFG contracts may include a minimum guarantee on the quality and amount of LFG to be delivered and/or a minimum guarantee on the amount of gas that will be consumed (known as a “take or pay” clause). Landfills should consider factors such as equipment and wellfield problems when agreeing to a minimum guarantee on gas delivery. In addition, landfills that are closed or closing in the near future should be cautious about setting unreasonable gas quality limits. Conversely, the energy user should include any routine plant shut downs in setting a minimum consumption guarantee.

<u>LFG Sales to an Electrical Generation Project</u>

These contracts are similar to those developed under a direct-use project application as discussed above. The contractual relationships between the entity that owns/operates the electrical generating facility and the purchaser of the electricity is provided in greater detail in Section 5.1.

High-Btu Sales

If the LFG is purified to natural gas pipeline standards, it can be injected into a natural gas distribution or transmission line. The concentration of carbon dioxide, oxygen, nitrogen, and other impurities (e.g., volatile organic compounds, hazardous air pollutants, hydrogen sulfide, siloxanes) must be reduced to levels required by the gas pipeline owners. When LFG is sold onto a distribution line to be used in the region serviced by the distribution company, the LFG is typically sold on a Btu basis to the distribution company at an indexed price. When LFG is sold onto a natural gas transmission line that transports gas over longer distances before acceptance by regional distribution companies, a more complicated contract may be required with the gas transmission line company; such contracts will address the provision of transmission services to the ultimate purchaser of the LFG and will also include contract provisions with the ultimate purchaser. The LFG may ultimately be sold to a natural gas supplier, marketer, or distributor at a fixed price or at an indexed natural gas price appropriate for the location or point of delivery. The environmental attributes also could be included as part of this contract.

5.3 Environmental Attribute Agreements

The LFG energy project developer can potentially sell a project's environmental attributes for additional revenue, or to provide more revenue to the landfill owner. Broadly, there are two types of environmental attributes:

- The destruction of LFG methane (direct).
- The displacement of fossil fuel use via generation of energy from LFG, a renewable energy source (indirect).

These attributes can be sold together or separately depending on the market in which they are sold and the nature of the contract entered into by the landfill owner or LFG energy project owner.

All participants in LFG energy projects (landfill owner/operator, developer, other market participants) should ensure that ownership of the environmental attributes, including the rights to the greenhouse gas emission reductions, are clearly defined. Historically, LFG energy projects were relatively clear about who owned the LFG rights; however, as new environmental markets evolved and new incentives were created (e.g., renewable energy certificates, tax credits, and recently greenhouse gas credits), contract language has not always been clear. For example, in contracts that pre-date the greenhouse gas markets, ownership of this attribute was usually not defined in the contract. A clear definition of which party has ownership of the LFG rights and each of the environmental benefits is critical for new project agreements and amendments to older agreements. The term "environmental attributes" is used to broadly define all of these benefits (including greenhouse gas), both known and those to be defined at some point in the future.

In addition, landfill owners or LFG energy project developers can often quality for renewable energy tax credits or other incentives to improve project financial feasibility. See Chapter 4, Section 4.2, and the U.S. EPA Landfill Methane Outreach Program (LMOP) online funding guide for information about various federal and state tax credits, tax exemptions, low-cost bonds, low-interest loans, and grants available to help finance LFG energy projects.

Greenhouse Gas Credits Derived From the Destruction of LFG

Methane is over 20 times more effective in trapping heat in the atmosphere than carbon dioxide over a 100-year period. The capture and destruction of the LFG, and its constituent methane, in a flare or other control device (e.g., internal combustion engine, gas turbine, boiler), results in a significant net reduction of greenhouse gas emissions. The greenhouse gas reductions achieved by the destruction of methane in LFG have market value and can be sold in voluntary and compliance markets. Essentially, an entity that wants, or is required, to reduce its greenhouse gas emissions can indirectly fund LFG collection and control projects through the purchase of greenhouse gas emission reduction credits from landfills. These greenhouse gas credits are traded in units of metric tons of carbon dioxide equivalent. Currently, greenhouse gas credits are traded in either a compliance or voluntary market; no single market nor single standard for the trade of greenhouse gas credit currently exists.

For a landfill's project to qualify for a greenhouse gas emission credit, the destruction of LFG must be "additional," meaning that the LFG must be collected and controlled voluntarily and cannot be required under regulations such as EPA's New Source Performance Standards (NSPS). Generally, a project does not qualify for greenhouse gas credits if the landfill is required to collect and control LFG under any local, state, or federal regulations for control of emissions, odors, and/or gas migration. Although buyers and markets vary, most require the LFG collection system to have been installed recently. Some buyers and markets will accept LFG collection systems that commenced operation as early as January 1, 1999.

Voluntary Markets. Most greenhouse gas transactions currently take place in the voluntary market, which is composed of markets, buyers, brokers, and aggregators who are voluntarily buying greenhouse gas credits with the goal of reducing the buyer's carbon footprint. The voluntary market currently comprises the Chicago Climate Exchange (CCX) and several options in the over-the-counter (OTC) market.[1]

The CCX is an integrated greenhouse gas emissions registry and trading system. Its members make a voluntary but legally binding commitment to reduce greenhouse gas emissions 4 percent from a baseline period (1998–2001) by 2006 and 6 percent by 2010. Greenhouse gas credits are verified by a third party and sold on CCX's Web-based trading system.

Participants in the OTC market, or firms investing in greenhouse gas credit projects, will sign agreements with landfill owners to obtain the right to the greenhouse gas credits and may provide the investment funds for the LFG collection system in some situations. The structure of these agreements is variable and will primarily depend on the level of equity, if any, provided by the party interested in procuring the greenhouse gas credits. For agreements where the greenhouse gas investment firm provides equity for all or part of a gas collection and control system, contract

[1] Forging a Frontier: State of the Voluntary Carbon Markets 2008. Ecosystem Marketplace & New Carbon Finance. May 8, 2008.

structures may provide ongoing revenue sharing or may allow the equity provider to recover their investment before revenue sharing with the landfill. Greenhouse gas agreements where equity is provided are typically longer-term agreements (up to 10 years) to minimize capital recovery risk by the investor. Simple greenhouse gas credit purchase agreements where significant equity is not provided can have a much wider range in agreement length. These non-equity greenhouse gas purchase agreements may address the transaction of a discrete amount of previously generated greenhouse gas credits, or may provide a longer-term (or forward) agreement for the rights to future greenhouse gas credit generation.

Because the voluntary greenhouse gas market is relatively new, no standardized methodology or protocol exists for determining eligibility of these credits. These voluntary markets and buyers operate using several different standards and protocols for determining project eligibility and verifying the greenhouse gas credits. A *standard* is the overall framework of a greenhouse gas program), whereas a *protocol* is a specific set of requirements that outline how greenhouse gas credits are developed for a specific project, such as an LFG energy project. Carbon standards include Voluntary Carbon Standard, Gold Standard, GE-AES Greenhouse Gas Services, and California Climate Action Registry. Protocols outline project eligibility, monitoring, recordkeeping, quantification, and reporting requirements. Greenhouse gas methodologies applicable to landfill projects in the voluntary markets currently include:

- California Climate Action Registry.
- Clean Development Mechanism (CDM) Consolidated Baseline and Monitoring Methodology for Landfill Gas Project Activities and CDM Methodological Tool to Determine Project Emissions from Flaring Gases Containing Methane.
- EPA Climate Leaders.
- GE-AES Greenhouse Gas Services.

Once the methane destruction from the LFG energy project has been quantified using the selected protocol, it must be converted into metric tons of carbon dioxide equivalent for trading. To do this, the amount of methane destroyed is multiplied by the global warming potential of methane, which can range from 21 to 25 depending on which greenhouse gas standard or protocol is used. Once a third party has verified the greenhouse gas credits, they may become verified emission reductions (VERs), carbon financial instruments (CFIs), or other protocol-defined instrument, depending on the market or the protocol used by the buyer.

Since most voluntary greenhouse gas transactions are not public information, the value for these greenhouse gas credits is not well established. According to a 2008 report,[2] average prices in 2007 for the CCX and OTC markets were $3.15 and $6.10 per metric ton of carbon dioxide equivalent, respectively. Prices within these two markets ranged from $1.62 to $300, with the $300 price observed on a single transaction only. The greenhouse gas credits generated by the voluntary

[2] Forging a Frontier: State of the Voluntary Carbon Markets 2008. Ecosystem Marketplace & New Carbon Finance. May 8, 2008.

collection and destruction of LFG at a landfill can be a significant revenue stream for the landfill owner of the LFG rights, as described in Chapter 4.

Compliance Markets. Compliance markets also being established in some states and regions of the United States. The Regional Greenhouse Gas Initiative (RGGI) is a cooperative effort by Northeastern and Mid-Atlantic states to reduce carbon dioxide emissions in the region. Participating states include Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. RGGI states are proposing to regulate carbon dioxide emissions from power plants through a regional cap-and-trade system. RGGI has established its own emissions trading program and a specific methodology for landfills to provide greenhouse gas offsets to this market.

California enacted a bill (AB-32) in 2006 that requires the Air Resources Board to establish rules to reduce greenhouse gas emissions. More information is available in a fact sheet from the California Environmental Protection Agency. The Western Climate Initiative — including Arizona, California, Montana, New Mexico, Oregon, Utah, and Washington, and Canadian provinces — is working to develop a regional greenhouse gas reduction program, including a cap and trade system. As these and other mandatory programs are developed they might create additional revenue streams, depending on whether the final rules allow landfills to provide greenhouse gas offsets.

Renewable Energy Attributes of LFG Energy Projects

LFG energy project developers/owners have opportunities to sell the renewable energy attributes of an LFG electricity project through several potential markets. Transactions in these markets provide value based on the reduction in use of fossil fuels to create energy (electrical or thermal) when LFG energy projects are implemented.

Renewable Energy Certificates. Many states have or are adopting Renewable Portfolio Standards (RPS). A state RPS requires an electrical supplier, provider, or distributor who sells to retail customers (i.e., an “electric services provider”) to include a minimum percentage of electricity from renewable generation. Typically, the electric services provider can meet the minimum percentage by purchasing renewable generation attributes from anywhere within the state or regional electric control area. Many state RPS programs group or “tier” the various types of renewable technologies based on which technologies a state wants to encourage. The RPS requirements are creating competitive markets for renewable attributes from renewable energy projects, including LFG-fired generation. Renewable energy certificates (RECs) are the tradable units that allow electric services providers to meet RPS requirements; a typical REC represents the environmental attributes of 1 megawatt-hour of electrical generation delivered to the grid. Pricing for RECs varies greatly by state, depending on the RPS regulations and supply and demand for a given renewable generation technology. RECs can also be sold through voluntary markets. This is more commonly done in states without RPS requirements or access to RPS programs within the region. LFG energy project developers and owners should investigate their options to sell RECs generated by the project and should consider obtaining the assistance of a broker or consultant to maximize REC value. The U.S. EPA Green Power Partnership Web site has more information on RECs.

Greenhouse Gas Displacement Credits. An LFG energy project can generate greenhouse gas emissions reduction credits by displacing more carbon-intensive forms of electric generation on the grid, such as coal and natural gas. Typically, LFG electricity-generating projects may not simultaneously sell RECs and obtain greenhouse gas emission reduction credits for the displacement of fossil fuels, because this is considered selling the same environmental attribute twice. However, LFG electricity projects that do not sell RECs (and do not sell the renewable attributes of the energy to their power purchaser by other means) can receive greenhouse gas emissions reduction credits for the destruction of the LFG if their power sales agreements allow for such sales. Additionally, some programs provide greenhouse gas credits for the displacement of fossil fuel use by LFG energy projects that produce thermal energy.

Agreements to sell renewable energy attributes of LFG energy projects can improve the financial feasibility of LFG energy projects, so landfill owners, LFG energy project developers, and investors should carefully scrutinize contracts and agreements regarding ownership and sale of these attributes.

5.4 Overview of Federal Regulations and Permits

The following section discusses federal regulations that may pertain to LFG energy projects. Landfills and LFG energy projects can be subject to air quality, solid waste, and water quality regulations and permitting requirements. The federal regulations are presented in general terms because individual state/local governments typically develop their own regulations for carrying out the federal mandates. Specific requirements may therefore differ among states. Further information for selected states is available in LMOP's State Primers. Project developers will need to contact relevant federal agencies and state agencies for more detailed, current information and to obtain permit applications for various types of construction and operating permits.

Clean Air Act (CAA)

The CAA regulates emissions of pollutants to protect the environment and public health. The CAA contains four provisions that may affect LFG energy projects: (1) NSPS and Emission Guidelines (EG), (2) National Emission Standards for Hazardous Air Pollutants (NESHAP), (3) New Source Review (NSR) permitting, and (4) Title V permitting.

NSPS and EG for Municipal Solid Waste (MSW) Landfills. LFG energy projects can be part of a compliance strategy to meet EPA's emission standards for LFG. MSW landfills meeting certain design capacity, age, and emissions criteria are required to collect LFG and either flare it or use it for energy. Under the NSPS and EG, large landfills that are greater than or equal to 2.5 million megagrams (Mg) and 2.5 million cubic meters in design capacity and have estimated emissions of non-methane organic compounds (NMOCs) of at least 50 Mg per year must reduce their emissions of LFG. The regulations identify NMOCs as a surrogate for LFG. Therefore, the emission reductions required in the rules are specified as reductions of NMOC. Landfills can use flares or energy recovery projects to meet the emission reduction requirements. LFG emissions were targeted in these rules because of the potential negative impact on human health and the environment from the volatile organic compounds contained in the gas. In addition, the contribution of LFG to local smog formation, local odors, and potential for explosions or landfill fires were included in the decision-making process. LFG energy projects reduce these health and environmental impacts.

For landfills that commenced construction, reconstruction, or modification on or after May 30, 1991 ("new landfills") the NSPS (40 CFR Part 60 Subpart WWW) apply. For older landfills that received waste after November 8, 1987 ("existing landfills"), the EG (40 CFR Part 60 Subpart Cc) apply. The collection and control requirements in each of these standards are the same; only the start of the compliance clock differs. However, the federal NSPS directly applies to new landfills, whereas the EG for existing landfills are implemented through either a federal plan or EPA-approved state plans. Individual state plans must be similar to, but might not be identical to, the EG. Therefore, landfills and developers should review the applicable state rules for existing landfills.

The final regulations for NSPS/EG can be found in the Federal Register, March 12, 1996, Vol. 61, No. 49, pages 9,905 to 9,944; amendments/corrections can be found in the Federal Register, February 24, 1999, Vol. 64, No. 36, pages 9,257 to 9,262. Complete regulations including the amendments are contained in the Code of Federal Regulations (CFR) subparts listed above. Additional clarifications and amendments have been proposed but are not yet final: see the Federal Register, September 8, 2006, Vol. 71, No. 174, pages 53,271 to 53,293 and the Federal Register, May 23, 2002, Vol. 67, No. 100, pages 36,475 to 36,481. These Federal Register notices and future proposed and final amendments to the NSPS and EG are available on the landfill page of EPA's Air Toxics Web site.

The NPSP and EG require collection and control of LFG at landfills meeting both of the following criteria:

- Capacity — maximum design capacity greater than or equal to 2.5 million Mg (about 2.75 million tons) and 2.5 million cubic meters. (Note that reporting is required for all facilities that meet this criterion, even if they do not meet the emission criterion.)

- Emissions — annual estimated uncontrolled NMOC emission rate is greater than 50 Mg (about 55 tons) per year.

Landfills that meet these criteria must install and operate LFG collection systems as described in the rule. The collected LFG can either be (1) combusted in an open flare that meets design and operating specifications in the rule or (2) combusted in an enclosed combustor (e.g., enclosed flare, boiler, internal combustion engine, or gas turbine) that achieves 98 percent NMOC destruction or 20 parts per million by volume NMOC concentration at the combustion device outlet. A third alternative is to treat the LFG prior to combustion for energy recovery. If the gas is treated, then the energy recovery device does not need to meet the NMOC emission limits or emissions testing requirements. For information on whether the level of treatment being considered for an LFG energy project allows for compliance using this rule option, contact the state air agency or the EPA regional office.

NESHAP. LFG energy projects can be part of a compliance strategy to meet EPA's landfill NESHAP. Under this rule, landfills meeting certain design capacity, age, and emissions criteria are required to collect LFG and to either flare it or use it for energy.

The regulations for MSW landfills under the NESHAP (40 CFR Part 63 Subpart AAAA) affect the same landfills and have the same control requirements as the NSPS/EG. Landfills with design capacities of at least 2.5 million Mg and 2.5 million cubic meters and estimated uncontrolled emissions of NMOCs of at least 50 Mg per year are required to collect and treat or control emissions of LFG. These control requirements are the same as the NSPS/EG with one exception — large landfills (i.e., those that exceed the 2.5 million Mg and 2.5 million cubic meters thresholds) that operate part or all of the landfill as a bioreactor must install collection and control systems for the bioreactor earlier than would be required by the NSPS, even if total estimated emissions do not yet exceed 50 Mg/year. The control systems may also be removed from bioreactors earlier. Bioreactors generate LFG more quickly than conventional landfills, but also generate the gas for a shorter period of time.

The NESHAP also contain more record-keeping and reporting requirements than the NSPS. Landfills that are required to collect and control LFG must develop a startup, shutdown, and malfunction (SSM) plan and must report SSM events. The NESHAP also require semi-annual compliance reporting, instead of the annual reporting required by the NSPS. The NESHAP define types of deviations from the standards that must be reported in the semi-annual reports (for example, periods when monitored control device operating parameters are outside of specified ranges). The final regulations for NESHAP can be found in the Federal Register, January 16, 2003, Vol. 68, No. 11, pages 2,227 to 2,242, available on the EPA Air Toxics Web site landfill page. The final NESHAP, including any amendments, are also published in the CFR subpart previously listed.

Overview of NSR Permitting. New LFG energy projects may be required to obtain construction permits under NSR. Depending on the area in which the project is located, obtaining these permits may be the most critical aspect of project approval. The combustion of LFG results in emissions of carbon monoxide, oxides of nitrogen, and particulate matter. Requirements vary for control of these emissions depending on local air quality. Applicability of the NSR permitting requirements to LFG energy projects will depend on the level of emissions resulting from the technology used in the project and the project's location (i.e., attainment or nonattainment area).

CAA regulations require new stationary sources and modifications to existing sources of certain air emissions to undergo NSR before they begin construction. The purpose of these regulations is to ensure that sources meet the applicable air quality standards for the area in which they are located. Because these regulations are complex, a landfill owner/operator may want to consult an attorney or expert familiar with NSR for more information about permit requirements.

The CAA regulations for attainment and maintenance of ambient air quality standards regulate six criteria pollutants: ozone, nitrogen dioxide, carbon dioxide, particulate matter, sulfur dioxide, and lead. The CAA authorizes EPA to set both health- and public welfare–based national ambient air quality standards (NAAQS) for each criteria pollutant. Areas that meet the NAAQS for a particular air pollutant are classified as being in "attainment" for that pollutant and those that do not are in "nonattainment." Because each state is required to develop an air quality implementation plan (called a State Implementation Plan or SIP) to attain and maintain compliance with the NAAQS in each Air Quality Control Region within the state, specific permit requirements will vary by state. (See 40 CFR 51.160-51.166 for more information on the requirements for developing SIPs including processes for review of new sources and modifications to ensure that they do not interfere with attaining or maintaining the NAAQS.)

The location and size of the LFG energy project will dictate what kind of construction and operating permits are required. If the landfill is located in an area that is in attainment for a particular pollutant, the LFG energy project may have to undergo Prevention of Significant Deterioration (PSD) permitting. Nonattainment area permitting is required for those landfills that are located in areas that do not meet the NAAQS for a particular air pollutant. Furthermore, the estimated level of emissions from the project determines whether the project must undergo major NSR or minor NSR. The requirements of major NSR permitting are greater than those for minor NSR. The following provides more detail on new source permits:

PSD Permitting. PSD review is used in attainment areas to determine whether a new or modified emissions source will cause significant deterioration of local air quality. Permit applicants must determine PSD applicability for each individual pollutant. For each pollutant for which the source is considered major, the PSD major NSR permitting process requires that the applicants determine the maximum degree of reduction achievable through the application of available control technologies. Specifically, major sources may have to undergo any or all of the following four PSD steps:

- Best available control technology (BACT) analysis.
- Monitoring of local air quality.
- Source impact analysis/modeling.
- Additional impact analysis/modeling (i.e., impact on vegetation, visibility, and Class I areas). (See 40 CFR Part 52.21 for more information on PSD.)

Minor sources and modifications are exempt from this process, but these sources must still obtain state construction and operating air permits. Contact the state agency for details and applications.

Nonattainment NSR Air Permitting. A source in an area that has been designated in nonattainment for one or more of the six criteria pollutants may be subject to the nonattainment classification for such pollutants. Ozone is the most pervasive nonattainment pollutant and the one most likely to affect LFG energy projects. Because oxides of nitrogen contribute to ambient ozone formation, ozone nonattainment can lead to stringent control requirements for oxides of nitrogen emitted from LFG energy projects. A proposed new emissions source or modification of an existing source located in a nonattainment area must undergo nonattainment major NSR if the new source or the modification is classified as major (i.e., if the new or modified source exceeds specified emissions thresholds). To obtain a nonattainment major NSR permit for criteria pollutants, a project must meet two requirements:

- Must use technology that achieves the lowest achievable emissions rate (LAER) for the nonattainment pollutant.

- Must arrange for an emissions reduction at an existing combustion source that offsets the emissions from the new project at specific ratios.

Title V Operating Permit Process. Many LFG energy projects must obtain operating permits that satisfy Title V of the 1990 CAA Amendments. Any LFG energy plant that is a major source, or is part of a major source, as defined by the Title V regulation (40 CFR Part 70), must obtain an operating permit.

Title V of the CAA requires that all major sources obtain new federally enforceable operating permits. Each major source must submit an application for an operating permit that meets guidelines spelled out in individual state Title V programs. The operating permit describes the emission limits and operating conditions that a facility must satisfy and specifies the reporting requirements that a facility must meet to show compliance with all applicable air pollution regulations. Therefore, the Title V permit will incorporate the specific requirements of the NSPS, EG, NESHAP, PSD, and/or nonattainment NSR that have been determined to apply to the individual LFG energy project. A Title V operating permit must be renewed every five years.

Resource Conservation and Recovery Act (RCRA) Subtitle D

Before an LFG energy project can be developed, all RCRA Subtitle D requirements (i.e., requirements for non-hazardous solid waste management) must be satisfied. In particular, methane is explosive in certain concentrations and poses a hazard if it migrates beyond the landfill facility boundary. LFG collection systems must meet RCRA Subtitle D standards for gas control.

Since October 1979, federal regulations promulgated under Subtitle D of RCRA require controls on the migration of LFG. In 1991, EPA promulgated landfill design and performance standards. These newer standards apply to MSW landfills that were active on or after October 9, 1993. Specifically, the standards require monitoring of LFG and establish performance standards for combustible gas migration control. Monitoring requirements must be met at landfills not only during their operation, but also for 30 years after closure.

Landfills affected by RCRA Subtitle D are required to control gas by establishing a program to periodically check for methane emissions and prevent off-site migration. Landfill owners and operators must ensure that the concentration of methane gas does not exceed:

- Twenty-five percent of the lower explosive limit for methane in facilities' structures.
- The lower explosive limit for methane at the facility boundary.

Permitted limits on methane levels reflect the fact that methane is explosive within the range of 5 to 15 percent concentration in air. If methane emissions exceed permitted limits, corrective action (i.e., installation of an LFG collection system) must be taken. Subtitle D may give some landfills an impetus to install energy recovery projects in cases where a gas collection system is required for compliance (see 40 CFR Part 258 for more information).

National Pollutant Discharge Elimination System (NPDES) Permit

LFG energy projects may need to obtain NPDES permits for discharging wastewater that is generated during the energy recovery process. LFG condensate forms when water and other vapors condense out of the gas stream due to temperature and pressure changes within the LFG collection system. This wastewater must be removed from the collection system. In addition, LFG energy projects may generate wastewater from system maintenance.

NPDES permits regulate discharges of pollutants to surface waters. The authority to issue these permits is delegated to state governments by EPA. The permits, which typically last five years, limit the quantity and concentration of pollutants that may be discharged. To ensure compliance with the limits, permits require wastewater treatment or impose other operating conditions. The state water offices or EPA regional office can provide further information on these permits.

The permits are required for three categories of sources and can be issued as individual or general permits. An LFG energy project would be included in the "wastewater discharges to surface water from industrial facilities" category and would require an individual permit. An individual permit application for wastewater discharges typically requires information on:

- Water supply volumes
- Water utilization
- Wastewater flow
- Characteristics and disposal methods
- Planned improvements
- Storm water treatment
- Plant operation
- Materials and chemicals used
- Production
- Other relevant information

Clean Water Act (CWA) Section 401

LFG energy projects may need CWA Section 401 certification for constructing pipelines that cross streams or wetlands. LFG recovery collection pipes or distribution pipes from the landfill to a nearby end user may cross streams or wetlands. When construction or operation of such pipes causes any discharge of dredge into streams or wetlands, the project may require CWA Section 401 certification.

The applicant must obtain a water quality certification from the state in which the discharge will originate. The certification should then be sent to the U.S. Army Corps of Engineers. The certification indicates that such discharge will comply with the applicable provisions of Sections 301, 302, 303, 306, and 307 of the CWA.

Other Federal Permit Programs and Regulatory Requirements

The following are brief descriptions of how other federal permits could apply to LFG energy project development:

- RCRA Subtitle C could apply to an LFG energy project if it produces hazardous waste. While some LFG energy projects can return condensate to the landfill, many dispose of it through the public sewage system after some form of on-site treatment. In some cases, the condensate may contain high enough concentrations of heavy metals and organic chemicals for it to be classified as a hazardous waste, thus triggering federal Subtitle C regulation.

- The Historic Preservation Act of 1966 or the Endangered Species Act could apply if power lines or gas pipelines associated with a project infringe upon a historic site or an area that provides habitat for endangered species.

- Requirements of the Uniform Relocation Assistance and Real Property Acquisitions Act of 1970, as amended, (Uniform Act) will apply to LFG energy projects, if federal funds are used for any part of project design, right-of-way acquisition, or construction. The Federal Highway Administration is the lead agency for issues concerning the Uniform Act.

Project developers will need to contact relevant federal, state, and local agencies for more detailed information on how the various federal, state, and local regulations would apply to a particular LFG energy project.

6. Evaluating and Working With Project Partners

Chapter Overview

The purpose of this chapter is to help landfill owners, landfill gas (LFG) energy project developers, energy end users, and the various partners involved in an LFG energy project understand the roles each can play in contributing to a successful LFG energy project. This chapter outlines how landfill owners can find and evaluate project partners and discusses the roles of each partner during project development. It covers both projects that are "self-developed" by the landfill owner and projects that use an outside energy project developer. The chapter also discusses LFG energy project partnering from an end user's perspective, including benefits, considerations, and evaluation techniques end users will want to consider before selecting partners and entering into agreements (see Section 6.5).

6.1 Decision Time: Project Developer or Self-Develop?

Once the decision is made to initiate an LFG energy project, the next step is to determine who develops, manages, and operates the project. Two primary models can be followed in structuring the development, ownership, and operation of an LFG energy project:

- A landfill owner/operator can self-develop the project and operate the LFG energy project with landfill personnel. The landfill owner directly hires individual consultants and contractors to fulfill each role that the landfill personnel cannot perform themselves.

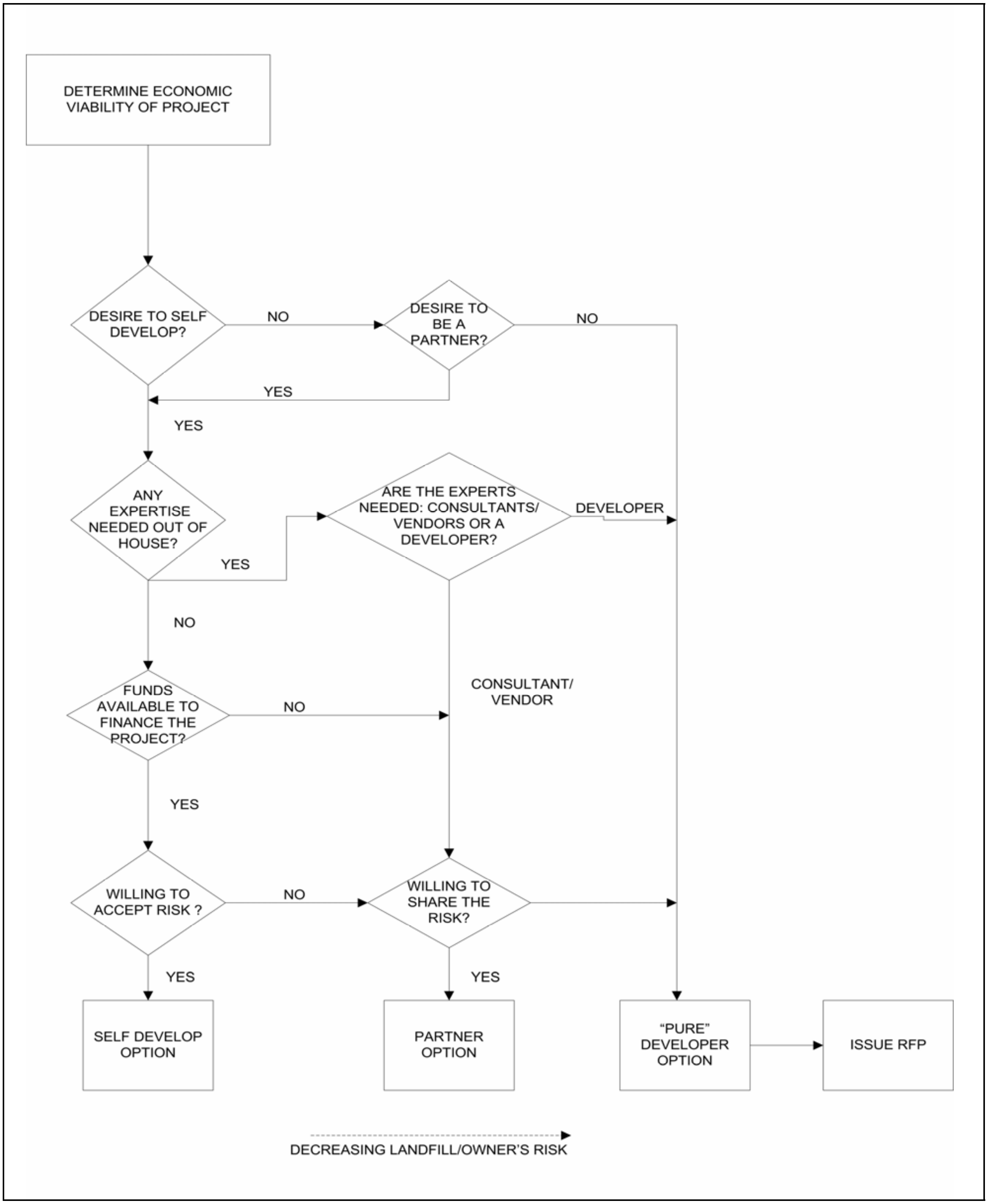
- An outside project developer can finance, construct, own, and operate the LFG energy project.

There are also hybrid approaches to developing an LFG energy project, but they all draw on the same principles presented in this chapter.

In any case, the landfill, energy end user, and LFG energy project owner will need assistance from outside partners. These partners typically are consulting engineers, lawyers, contractors, regulatory and planning agencies, community members, and financial professionals. (For a full list of Landfill Methane Outreach Program [LMOP] Partners, including these types of organizations, see the LMOP Web site). The involvement of multiple partners helps to ensure timely development of an LFG energy project that is financially feasible and benefits the environment and the local community.

Figure 6-1 illustrates a process for determining whether to self-develop or to secure an outside project developer. Before the decision is made, the landfill owner should understand the steps that are necessary to self-develop a project, as listed in Box 6-1. They should also assess their willingness and expertise to undertake the steps listed in Box 6-1, and which of these steps will require assistance from partners.

Figure 6-1. The Project Developer/Partner Selection Process



Box 6-1. Some Steps to Self-Developing an LFG Energy Project

- *Determine LFG supply:* If the landfill owner has not already completed this step, the first self-development step will be to determine the LFG supply using calculations, computer modeling, and/or test wells.
- *Scope the project:* Includes early-stage tasks such as selecting a location for the equipment, sizing the energy output to the LFG supply, contacting potential energy customers, and preliminary selection of the prime mover.
- *Conduct feasibility analysis:* Includes detailed technical and economic calculations to demonstrate the technical feasibility of the project and estimate project revenues, costs, internal rate of return, payback period, and other measures of economic performance.
- *Design the plant, pipeline, or project.*
- *Select equipment:* Based on the results of the feasibility analysis, primary equipment is selected and vendors are contacted to assess price, performance, schedule, and guarantees.
- *Create a financial pro forma:* A financial pro forma updates the feasibility analysis with actual bids from vendors.
- *Negotiate the power sales or gas sales agreement:* The terms of the agreements must be negotiated with the purchasing electricity utility or end user.
- *Obtain all required environmental and site permits.*
- *Gain regulatory approval:* Some LFG energy projects must obtain approval from state regulators or certification by the Federal Energy Regulatory Commission.
- *Negotiate partnership agreement(s):* If project ownership is to be shared with partners or investors, then the project will require negotiation of ownership agreements.
- *Secure financing:* Requires specific expertise, depending on the type of financing used.
- *Contract with engineering, construction, and operating firms and negotiate contract terms.*

Decision Factors

In deciding whether to seek a project developer, the landfill owner should consider economics, technical expertise available to the landfill, and the level of risk the landfill is willing to accept.

Economics. Significant capital (upfront) costs are required to design, build, and operate an LFG energy project. In order to determine if the landfill owner has enough capital available, an economic feasibility study is prepared as described in Chapter 4. Results of this study are evaluated for capital needs, internal rates of return (IRR), and other financial needs. The landfill owner considers available capital and financing options (e.g., private financing or municipal bonds as described in Chapter 4) to determine if sufficient funding is available or can be obtained. If the landfill chooses to hire a developer, the developer would obtain the funding.

Expertise. To develop an LFG energy project, landfill owners will need to interact with partners who have a variety of specialized technical, financial, or legal expertise. One way to improve this interaction is to use a qualified project manager (PM). A qualified PM knows the landfill owner's operating and financial constraints, has the expertise and authority to direct work on the project, and must be able to make a significant time commitment to managing the project for a long period (often up to two years). If a landfill owner does not have a PM on staff, then he or she should consider contracting for an outside PM or hiring a project developer to perform this task.

Landfill owners might need to seek the expertise of consultants and contractors to design, build, and/or operate these LFG energy projects, especially if they plan to self-develop. A *consultant* can give landfill owners technical assistance on the design and technical recommendations regarding state and federal regulations and operation of the wellfield and energy project. *Contractors* can provide advice on how to build the LFG energy project, but their main responsibility is construction of the facility. After construction, a contractor, operation and maintenance (O&M) vendor, or consultant can operate the LFG energy project if the landfill owner decides not to operate the project using landfill personnel.

Risk Level. The amount of risk that the landfill owner is willing to accept is an important factor in deciding whether to self-develop the LFG energy project or seek a project developer who will assume much of the risk. Risks involved in LFG energy projects include:

- Construction
    - Cost overrun
    - Project delays
    - Failure of plant to meet performance criteria
    - Weather and seasonal implications
    - Work warrantees
- Equipment
    - Mechanical failures
    - Not meeting specifications
    - Not meeting emission requirements
    - Not configured for the corrosiveness of LFG
- Permitting
    - Excessive permit conditions/right of way
    - Public comments on draft permits
- Financial performance
    - Not having enough LFG
    - Maintenance downtime
    - Operation cost overrun
    - Project financing
    - Labor and material costs
    - Regulatory exposures

Other Reasons to Consider Using a Project Developer or to Pursue a Hybrid Option. Selecting a developer to manage, own, finance, and operate the LFG energy project reduces risks for a landfill owner. The developer also incurs the cost associated with an LFG energy project, so there is no net cost to the landfill owner. Other reasons for selecting a project developer are:

- The project developer's skills and experience may bring a project online faster.
- The developer may have numerous other LFG energy projects, which allow them the economies of scale to reduce capital and O&M costs.
- Some developers invest equity or have access to financing.
- The developer might possess a power sales agreement that was previously won and/or negotiated with a nearby electric utility.
- Bringing on a developer can simplify the project development process for the landfill owner, requiring less landfill staff time and expertise.
- In return for accepting project risks, the project developer retains ownership and control of the energy project and receives a relatively large share of the project profits. Note that developers may make decisions that tend to favor factors that increase energy revenues but not necessarily the landfill owner's priorities, such as managing LFG migration and emissions.

A turnkey project allows for a hybrid approach. With turnkey projects, the landfill owner retains energy project ownership, but the project developer assumes the responsibility for construction risk, finances, and building the facility. Once the LFG energy project is built and operating to project specifications, the developer then transfers operation of the LFG energy project to the landfill owner. In return, the landfill owner gives the project developer a smaller portion of the project proceeds, gas rights, and/or a long term O&M contract. The turnkey approach can be a "win-win" approach for both the project developer and the landfill owner since the developer retains responsibility of construction, development, and performance risk and the landfill owner assumes the financial performance risk.

Other Reasons to Consider Self-Developing a Project. On the other hand, there can be advantages to self-developing a project. For example, the landfill retains control and retains a larger share of the profits in return for accepting the risk. In addition, developing a project may be a rewarding challenge and opportunity for landfill staff, and such projects can foster good relationships with end users, other partners, and the community. Listed below are links to LMOP project profiles of successful self-developed projects:

- Prince George's County Correctional Facility
- Brown Station Road
- Jersey Shore Steel

In summary, the project developer, self-development, and hybrid approaches have all yielded successful LFG energy projects. The key is finding the approach that is best suited to the specific landfill and other participants involved in the project.

6.2 Finding and Evaluating an LFG Energy Project Developer

Finding an LFG Energy Project Developer

If the landfill owner decides to employ a developer, he or she investigates individual developers to determine which one meets their particular needs. Criteria to consider when evaluating developers' qualifications and capabilities include:

- Previous LFG energy project experience.
- A successful project track record.
- Financial offer to the landfill owner.
- Financial strength.
- In-house resources (engineering, finance, operation), including experience with environmental compliance and community issues.

Landfill owners can obtain background information on developers from annual reports, brochures, project descriptions, and discussions with references such as other landfill owners and engineers.

Another method of evaluating developers for a landfill owner is issuing a request for proposals (RFP). Although private landfill owners do not normally issue RFPs to developers, RFPs provide a competitive and fair basis of evaluation. An RFP needs to include all of the landfill owner's requirements, as well as information about the LFG resource. Landfills sometimes hire a consultant to help them develop and evaluate responses to an RFP. LMOP can provide landfill owners with example RFPs and can help distribute the RFP via LMOP's e-mail listserv.

Evaluating a Developer

After the landfill owner receives proposals from various developers, the next step is to evaluate the proposals, sometimes with the assistance of a consultant. When reviewing the proposals, landfill owners typically compare proposals or RFP responses in order to evaluate the developer's experience, technical approach, financial advantages to the landfill owner, business issues, and schedule for implementation. After evaluating the proposals, the landfill owner selects the developer that adds the most value and begins negotiations.

Various methods are available to evaluate proposals, ranging from a checklist to a ranking matrix listing the evaluation criteria with a scoring system.

Checklist. The simplest method is a checklist that lists the RFP requirements and evaluation criteria and has space to check whether or not each requirement is met. For a landfill owner who considers all RFP requirements to have equal importance, the checklist method may be sufficient.

Ranking Matrix. For a landfill owner who considers RFP requirements to vary in importance, a ranking matrix would be better to complete the evaluation. For example, if a landfill owner has failed in previous LFG energy attempts at their facility, making sure that the developer's approach is technically sound might be the most important factor in selecting a developer. However, for another landfill owner who feels an addition to the landfill's net income is most important, the royalty paid by the developer might be the more important requirement. No two landfill owners apply the same weight to evaluation criteria. Box 6-2 presents a list of potential evaluation criteria landfill that owners use to evaluate an LFG energy project developer.

Box 6-2. Example Evaluation Criteria for Selecting an LFG Energy Project Developer

- Project cost
  - Capital costs
  - O&M costs
- Project experience
  - Plant design and construction experience
  - Experience with state regulations
  - LFG energy experience
  - References and track record
- Project approach
  - Technical approach
  - Project feasibility (likelihood of success)
  - Odor control and other environmental advantages or impacts
- Financial advantages to the landfill owner
  - Price per MMBtu for the gas
  - Up-front payments
  - Revenue sharing
  - Sharing of greenhouse gas, renewable energy, or other credits
  - Planned expenditures by the developer on the wellfield
- Business considerations
  - Developer or parent net worth
  - Developer or parent annual revenue
  - Developer-assumed LFG quality and availability risk
- Time frame to implement
  - Scheduled startup date
  - Penalties or termination issues for missing startup date

6.3 Self-Developing: Finding and Evaluating Project Partners

If a landfill owner decides to self develop, the landfill owner partners with persons or institutions that provide assistance during the development and operation stages of the LFG energy project. These can include financial partners, such as bankers and accountants; professional consultants, such as consulting engineers and lawyers; and contactors, such as equipment manufacturers and construction contactors. For this scenario, the landfill owner manages, owns, and operates the LFG energy project.

The process for contracting with a partner is the same as contracting with a developer. The landfill owner often issues an RFP to prospective partners. Each RFP is tailored to the type of partners and role the landfill needs each partner to perform in developing the energy project. The RFP includes the equipment the partner must supply and the services and activities each partner is required to perform. The landfill owner evaluates the proposals by reviewing the submitter's project experience, project approach, and proposed cost. The specific evaluation criteria will need to be customized depending on the type of partner and the specific statement of work in the RFP, but general criteria include:

- Project cost
- Project experience
- Project approach
- Time frame to implement

Finally, the landfill owner uses the same methods described in "Evaluating a Developer" (in Section 6.2) to review the proposals and award the project to the prospective partner.

6.4 Project Interaction Among Partners

LFG energy project owners who self-develop will contract with some or all of the following types of partners during the evaluation process and during development of the LFG energy project:

- Financial partners
- Professional partners
- End users
- Contractors
- Government and community partners

They also interact with a variety of other partners including regulatory and planning agencies and community groups. Each of these partners provides financial, professional, regulatory, and contracting services to make the project successful.

Financial Partners

Financial partners are persons or institutions that assist the LFG energy project owner (either the developer or the landfill owner who self-develops a project) by loaning or providing adequate finances, preparing tax credits, and tracking finances associated with the LFG energy project. Typical financial partners are:

- Tax creditors
- Bankers
- Accountants

Table 6-1 describes how each one of these partners are involved in the LFG energy project.

Table 6-1. Financial Partners for LFG Energy Projects

Partner	Purpose
Tax creditor	Assists LFG energy project owners in applying for available tax credits, such as IRS section 45 tax credits or state or local renewable energy tax credits.
Banker/ financier	Helps developers/landfill owners fund the LFG energy project.
Accountant	Assists LFG energy project owners by tracking the finances involved in project development. Tracks revenues for both the landfill owner and developer.

Even if a landfill owner uses a developer, he or she will still need to interact with these partners. For example, the landfill owners might provide information on the quantity of LFG generated so that tax creditors can perform calculations needed to determine tax credits and bankers can determine if they will make a loan.

Professional Partners

Professional partners are persons or institutions that provide legal, marketing, or technical services to the LFG energy project owner. Typical professional partners for an LFG energy project are listed below and described in Table 6-2. Depending on the LFG energy project owner's in-house capabilities, professional partners may provide some or all of these services:

- Engineering consultants
- Legal assistance
- Communication and public relations services

Landfills that use a developer will still need to interact with the professionals listed in Table 6-2. For example, landfill owners will probably need to give the consulting engineer information on landfill design and gas collection system design, site maps and surveys, permit requirements to be sure that this information is taken into account in designing, constructing, and operating the LFG energy project. The landfill owner will also interact with lawyers to be sure their interests are protected during negotiations and contract development. Landfill personnel who operate the wellfield will need to work closely with partners who operate the LFG energy project to ensure that the required amount and quality of gas is provided to the project and that applicable air regulatory requirements are met.

Table 6-2. Professional Partners for LFG Energy Projects

Partner	Purpose
Consulting engineers	Provide technical services to the developer or landfill owner. Can help developers prepare the proposal to the landfill owner. May assist the developer or the landfill owner in designing and constructing the LFG energy project. Can help ensure that the project is in regulatory compliance.
Lawyers	Draft and review a wide range of contacts (e.g., contracts protecting the LFG energy project owner from liability, the contract between a developer and the landfill owner, contracts between the LFG energy project owner and the energy end user, contracts with other consultants or contractors). Review legal aspects of tax credits, project structures, and other legal aspects of the work.
Communication specialists/ public relations firms	Can help foster interaction with community partners, publicize the environmental benefits of the LFG energy projects, or prepare educational materials about it.

End Users

The end user is the person or institution that purchases the generated energy from the LFG energy project owner. Some end users purchase LFG (that has undergone appropriate treatment) for direct use in the boilers, heaters, kilns, furnaces, or other combustion equipment at their facilities. Others use LFG to produce electricity, as a feedstock for a chemical process, or for another beneficial use. Alternatively, instead of purchasing the LFG, the end user may purchase the electricity that the LFG energy project owner generates from the LFG.

The end user provides the LFG energy project owner with his or her fuel requirements (e.g., LFG quantity, LFG energy content, pressure, temperature) or electricity requirements, so that the LFG energy project owner can design and operate LFG energy project to meet the end user's needs. The end user will enter into a contract to purchase the LFG or electricity. A close working relationship between the landfill owner, developer (if there is one), and end user must continue after the project becomes operational to ensure project success. Section 6.5 provides further information on end-user perspectives.

Contractors

Contractors are partners whom the LFG energy project owner employs to implement specific activities such as constructing the facility, providing the equipment, or conducting regulatory compliance testing. Table 6-3 describes the responsibilities of contractors.

Table 6-3. Contractor Partners for LFG Energy Projects

Partner	Purpose
Generator manufacturers	A developer or landfill owner approaches several manufacturers to determine which type of energy generation equipment best fits the design and operating requirements of the LFG energy project. Specifications of interest to the developer include low air emissions, low cost, operation efficiency, fuel requirements, O&M requirements, and output production. As a result, generator manufacturers provide the project owner with data that show whether the equipment meets the project requirements. Based on this information, the developer selects the generator and the manufacturer provides it.
Energy generation plant operators	Developers typically employ operators who operate and maintain the LFG energy plant. As a result, they interact with both the landfill owner and developer. The plant operator usually records and provides the energy output data, air emission data, testing data and maintenance information to the project owner.
LFG treatment system manufacturers	Developers or landfill owners often need LFG treatment systems to filter, remove moisture or contaminants from, and compress the LFG. They approach manufacturers for design and product specification assistance. These manufacturers work with the developer, the consultant, the end user, and the landfill owner to design, supply, and assemble the proper equipment to treat the LFG.
Construction contractors	The developer or the landfill owner who self-develops an energy project employs the construction contractor. The contractor builds the facility. Interactions between the parties include project bidding, awarding contract, construction activities, and initial project performance period (i.e., the time during which the system is tested to determine if it meets project performance requirements).
Testing laboratories	Developers or landfill owners employ testing laboratories to perform any emissions testing required by regulations or permits to ensure that the energy generation equipment does not emit more than the allowable levels.
Wellfield operator	Landfill owners or developers often employ a wellfield operator to ensure that the landfill is in compliance with the air permit. The wellfield operator operates and maintains the gas extraction wellfield and makes tuning adjustments necessary to efficiently collect the LFG. Following each wellfield tuning event, the wellfield operator communicates the results to both the landfill owner and developer, who need this information to meet LFG energy project operation requirements and/or to comply with air permits.

The landfill owner will be closely involved with contractors even if a developer constructs, owns, and operates the energy project. For example, the construction contractor works on the landfill owner's property. Therefore, the contractor follows the landfill's rules and operational requirements. During construction, the contractor may need to interrupt daily waste placement or LFG management operations at the site; therefore, the landfill owner and contractor are in constant communication. After project startup, the landfill owner must provide the required amount of gas to the LFG energy project, and the LFG must meet quality specifications. The landfill is typically responsible for managing operation of the wellfield to deliver the gas, and must balance the wellfield to maintain both air permit requirements and LFG energy production needs. If there is temporarily not enough LFG, the landfill owner notifies the generation plant operator so that the plant operator can make the proper adjustments. The generation plant operator will also notify the landfill owner if one or all of the generators are not operating, since this usually requires the landfill owner to use a different method to control LFG emissions (e.g., with a backup flare).

Government and Community Partners

Regardless of whether the landfill owner chooses to hire a developer or to self-develop a project, the LFG energy project owners will need to work with various governmental and community partners, including regulatory and planning agencies and community organizations.

Regulatory and Planning Agencies. Regulatory partners are involved to ensure that the project complies with local, state, and federal regulations. They are often the partners that "make or break" a project. As a result, the LFG energy project owners and operators need to work closely with these partners to ensure success.

Regulatory and planning agencies provide regulatory guidance and the required permits to landfill and LFG energy project owners. When preparing applications for zoning or land use permits, air permits, and conditional use permits, LFG energy landfill owners or developers engage with regulatory and planning agency partners, such as:

- State environmental regulatory agencies
- State energy agencies, public utility commissions
- County board members
- Local solid waste planning board
- Local zoning and planning department

These partners are involved primarily during the process of siting and permitting the facility. Discussions between the LFG energy project owner and regulatory agencies should begin early in the process to ensure that LFG energy project owners understand all the environmental and land use requirements and restrictions that will apply to the project and that the regulators' concerns are satisfied. The project owner will need to provide information showing that the project will meet emission limits and other requirements, and will need to demonstrate compliance once the project becomes operational. Each state may have different regulations and procedures for these activities. Some of these regulations and procedures can be found at the following Web sites:

- LMOP State LFG Primers
- Database of State Incentives for Renewables and Energy
- Regulatory Requirements Database for Small Electric Generators

State and local agencies can also play an active role in encouraging environmentally and economically beneficial energy projects. LFG energy projects make use of a renewable energy resource, offset fossil fuel combustion, and may reduce odors and help improve local air quality. They can also create jobs and economic benefits to the community; in some cases, new businesses have located near a landfill to use the gas, providing further economic benefits. In recognition of these benefits, many states have created incentives for LFG energy and other renewable energy projects. Many state energy, environmental protection, and economic development agencies have partnered with LMOP to encourage LFG energy projects in their states. These LMOP State Partners can assist landfills and end users who want to develop projects.

Community Partners. Community partners are typically neighbors to the landfill, the general public, local businesses, and environmental and community organizations. It is important for LFG energy project owners to provide information to the community so that community partners understand how the LFG energy project might affect them, and so the LFG energy project owner understands any community concerns. LFG energy project owners can work with the community to address any concerns and to select a project that complies with community zoning and other ordinances and has environmental and economic benefits to the surrounding community. Unless there is significant opposition to the LFG energy project, community partners are mainly involved during the permitting process. When LFG energy project owners apply for the required permits (i.e., air and zoning permits), community members provide comments during a public comment period. During this public comment period, the community provides the LFG energy project owner or regulators with questions, concerns, or opposition to the proposed facility. Depending on the results of the public comment period, the permits are issued, modified, or rejected.

LFG energy project owners can work with community organizations and the media to help the public understand the benefits of an LFG energy project and to answer environmental, cost, and other questions that the community raises. LMOP provides an online Toolkit to help communicate the benefits of LFG energy and develop outreach materials. Involving community groups in LFG energy project planning can help ensure that the type of LFG energy project chosen is a good fit for their community and provides environmental and economic benefits to the community. LMOP's "Creating Green Energy in Your Community" brochure is a great tool for raising awareness and gaining support for LFG energy at the community level.

6.5 Evaluation of LFG Energy Projects and Partners — End User's Perspective

The purpose of this section is to assist potential LFG energy end users in evaluating landfills and LFG energy project owners. It includes:

- A summary of LFG energy project benefits to end users
- Issues to consider when entering agreements with landfills and LFG energy project owners
- Evaluating proposals and negotiating with landfill owners and LFG energy project owners

LFG Energy Project Benefits to End Users

LFG energy projects can provide environmental, economic, and energy benefits to end users.

Environmental benefits include the ability to meet air emission regulations and permit conditions, and a reduction in greenhouse gas emissions compared to using fossil fuels for energy. The end user may gain recognition as an environmental steward by utilizing a renewable energy resource that would otherwise be wasted.

End users can benefit from an LFG energy project economically. End users typically receive LFG at a lower cost than natural gas or other energy resources. Sometimes (depending on the project structure) end users receive IRS tax credits, greenhouse gas emission reduction credits, or renewable energy credits. For more information, see the Corporate Users section of LMOP's Web site.

LFG end users receive also receive energy benefits. LFG is continuously generated and therefore suitable for a range of energy applications including direct use and electricity generation. Electric utilities that obtain power from LFG broaden their resource base and can use the LFG to meet Renewable Portfolio Standards (RPS) requirements or receive credits for using a renewable fuel. For more information, see the Green Power section of the LMOP Web site.

Considerations

Before entering into or during contract negotiations, end users should perform due diligence on the landfill and prospective LFG energy project owner to ensure the most beneficial outcome. The end user needs to evaluate several aspects of the project to determine financial, regulatory, and other implications. The end user typically either hires a consultant to engage in this task or self-performs the due diligence. In either case, the end user reviews the issues listed below:

- Quality and quantity of fuel
- Reliability of fuel
- Public perception
- Time to develop the LFG energy project
- Retrofits of combustion and other equipment necessary at the end user's facility
- Effect of LFG energy project on the end user's air permit
- Equipment maintenance (e.g., boilers, internal combustion engines, gas turbines)
- Landfill owner and developer financial assurances
- Contractual terms

Evaluating and Negotiating Techniques

Evaluating and Negotiating With Potential Landfill Owners/Developers. After receiving proposals from various landfills, the end user evaluates and negotiates with the LFG energy project owner. Evaluation involves comparing the results of the due diligence study to the end user's requirements (i.e., financial goals, business objectives, and project schedule). Once this step is complete, the end user begins negotiating with the landfill owner or the LFG energy project owner, as appropriate, for purchasing the LFG. These negotiations may also involve lawyers, bankers, accountants, and consultants. If the end user finds a discrepancy with the project requirements, the end user discusses each discrepancy with the landfill owner or developer. Depending on the degree of these discrepancies, the end user negotiates a different price, requires the discrepancy to be repaired, or proposes an alternative.

Evaluating Potential Partners. End users engage in partnerships with consultants, financial professionals, and lawyers. Consultants provide technical recommendations to the end user about a range of project issues including environment and regulatory compliance, economic pro forma analysis, LFG quantity and quality, energy production, and equipment operation and maintenance. Financial professionals can include bankers, tax advisors, and financial planners. They may provide finances necessary to purchase the LFG gas, provide advice on obtaining tax credits, or assist with financial planning. In addition, they help end users obtain and receive grants, loans, and credits. Lawyers provide legal advice to the end user about LFG rights, contract agreements, and site leases.

To ensure that the LFG energy project is successful for the end user, the end user investigates potential partners for their past experience in LFG energy projects, project approach, financial proposal, and schedule and then enters into contracts with the selected partner(s). Throughout project development, the end user, landfill owner, and other partners work closely together to implement an LFG energy project that will result in environmental and economic benefits for the end user, the landfill owner, and the community.

Appendix 4-A.
Electricity Case Studies

The following case studies, obtained by running LMOP's LFGcost economic assessment tool, are example preliminary economic assessments for a 3 megawatt (MW) landfill gas (LFG) electricity project using internal combustion engines. The first case, named "Electricity 1" is a privately funded project at a landfill that already has an LFG collection and flaring system in place. A similar case for a landfill that does not have an LFG collection and flaring system and must include collection system and flare costs in the economic assessment is named "Electricity 2." Also included are several other cases, including projects that receive revenue through greenhouse gas credits or renewable energy certificates and projects that use municipal funding. The summary table below describes each case. The following pages present the actual output from LFGcost-Web.

Privately Developed Projects

Case Study Name	Project Description	Financing and Revenue Elements	Financial Results Summary
Electricity 1	• 3 MW engine project • No collection and flaring system required	• 20% down payment, 80% financed • 8% interest rate • 6¢/kWh (default) electricity price	Capital cost: $3,555,156 O&M cost: $470,328 NPV: $1,440,474 IRR: 25% NPV payback (years): 7
Electricity 2	• 3 MW engine project • LFG collection and flaring system required	• 20% down payment, 80% financed • 8% interest rate • 6¢/kWh (default) electricity price	Capital cost: $5,178,761 O&M cost: $826,671 NPV: ($1,721,074) IRR: -2% NPV payback (years): none
Electricity 3	• 3 MW engine project • LFG collection and flaring system required	• 20% down payment, 80% financed • 8% interest rate • 7.53¢/kWh electricity price calculated to achieve 10% IRR	Capital cost: $5,178,761 O&M cost: $847,944 NPV: $376 IRR: 10% NPV payback (years): 15
Electricity 4	• 3 MW engine project • LFG collection and flaring system required	• 20% down payment, 80% financed • 8% interest rate • 6¢/kWh (default) electricity price • $4/metric ton carbon dioxide equivalent credit revenue included	Capital cost: $5,178,761 O&M cost: $826,671 NPV: 1,364,007 IRR: 21% NPV payback (years): 9
Electricity 5	• 3 MW engine project • No collection and flaring system required	• 20% down payment, 80% financed • 8% interest rate • 6¢/kWh (default) electricity price • 2¢/kWh renewable energy credit included	Capital cost: $3,555,156 O&M cost: $470,328 NPV: $3,318,320 IRR: 47% NPV payback (years): 3

Municipality-Developed Projects

Case Study Name	Project Description	Financing and Revenue Elements	Financial Results Summary
Electricity 6	• 3 MW engine project • No collection and flaring system required	• 100% down payment using municipal budget • 6% discount rate • 6¢/kWh (default) electricity price	Capital cost: $3,555,156 O&M cost: $470,328 NPV: $4,590,440 IRR: 22% NPV payback (years): 6
Electricity 7	• 3 MW engine project • No collection and flaring system required	• 20% down payment, 80% bond-financed • 6% interest rate, 6% discount rate • 6% kWh (default) electricity price	Capital cost: $3,555,156 O&M cost: $470,328 NPV: $4,429,452 IRR: 40% NPV payback (years): 4
Electricity 8	• 3 MW engine project • LFG collection and flaring system required	• 100% down payment using municipal budget • 6% discount rate • 6¢/kWh (default) electricity price	Capital cost: $5,178,761 O&M cost: $826,671 NPV: ($718,079) IRR: 4% NPV payback (years): none
Electricity 9	• 3 MW engine project • LFG collection and flaring system required	• 20% down payment, 80% bond-financed • 6% interest rate, 6% discount rate • 6¢/kWh (default) electricity price	Capital cost: $5,178,761 O&M cost: $826,671 NPV: ($952,589) IRR: 1% NPV payback (years): none
Electricity 10	• 3 MW engine project • LFG collection and flaring system required	• 20% down payment, 80% bond-financed • 6% interest rate, 6% discount rate • 6.47¢/kWh electricity price calculated to achieve 6% IRR	Capital cost: $5,178,761 O&M cost: $833,248 NPV: $852 IRR: 6% NPV payback (years): 15

IRR: internal rate of return

kWh: kilowatt-hour

NPV: net present value

O&M: operation and maintenance

Case Study ID: Electricity 1

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Private Finance

LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Monday, December 15, 2008

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but can not be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Standard Reciprocating Engine-Generator Set	
Financial Results:		
Net Present Value:	$1,440,474	*(at year of construction)*
Internal Rate of Return:	25%	
Net Present Value Payback (yrs):	7	*(years after operation begins)*
Capital Costs:	$3,555,156	
O&M Costs:	$470,328	*(for initial year of operation)*

These financial results DO NOT include the costs associated with the LFG collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	5,155
($MMTCO_2E$):	2.08E+00
Average Annual	
(million ft^3 methane/yr):	344
($MMTCO_2E$/yr):	1.38E-01

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	2.33E-01
Average Annual ($MMTCO_2E$/yr):	1.55E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	5,400,000
Average Waste Acceptance (tons/yr):	270,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	110

Landfill Gas Generation, Collection, and Utilization

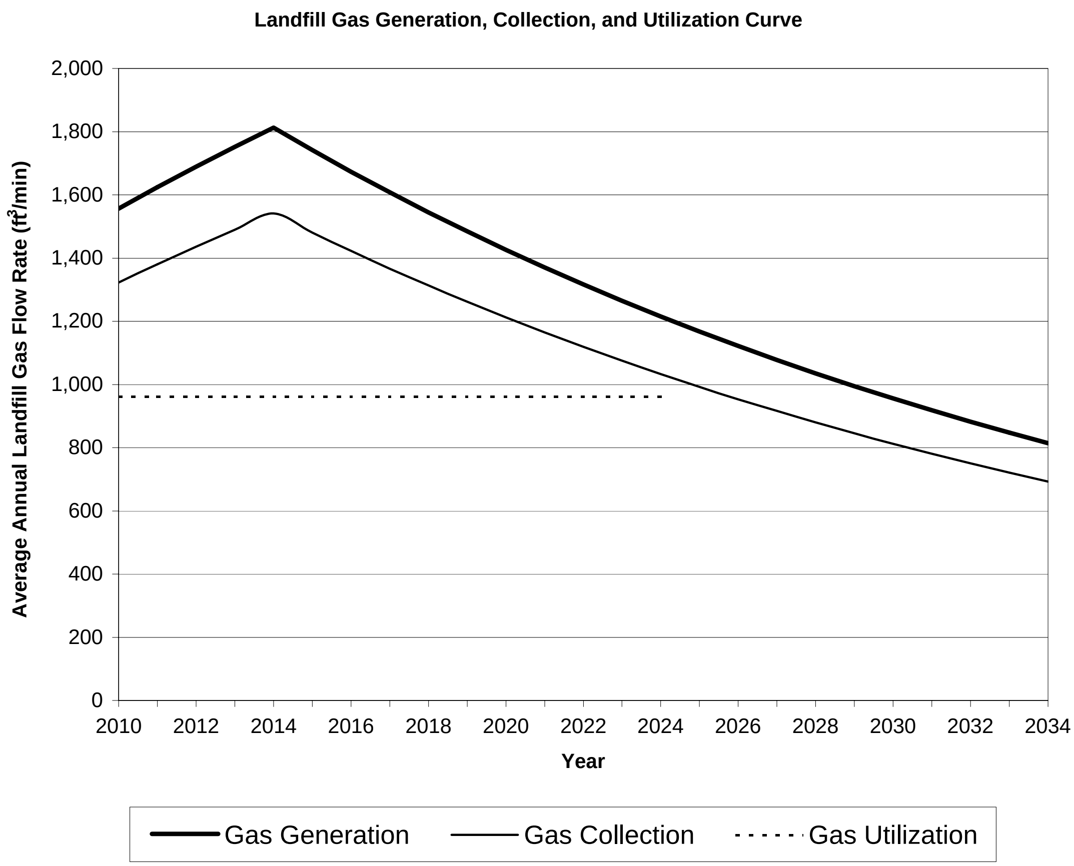
Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	1,215	
Annual Average:	1,539	
Maximum:	1,813	
Collected During Project Lifetime (ft^3/min):		
Minimum:	1,033	
Annual Average:	1,308	
Maximum:	1,541	
Project Size:	Minimum	
Design Flow Rate for Project (ft^3/min):	1,033	
Utilized by Project (ft^3/min):		
Annual Average:	961	
LFG Collection Efficiency:	85%	

Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	8.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	35.0%	
Discount Rate:	10.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	NOT Included	

Electricity Production and Sales Summary

Total Generation Capacity (kW):	2,787	
Average Generation (million kWh/yr):	20.890	*(during the life of the project)*
Initial Year Electricity Price ($/kWh):	0.06	


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft³/min)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

Case Study ID: Electricity 2

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Private Finance
Including Costs for Gas Collection and Flare
LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Monday, December 15, 2008

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but can not be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Project Start Year: 2010

Project End Year: 2024

Project Type: Standard Reciprocating Engine-Generator Set

Financial Results:

Net Present Value:	($1,721,074)	*(at year of construction)*
Internal Rate of Return:	-2%	
Net Present Value Payback (yrs):	None	*(years after operation begins)*
Capital Costs:	$5,178,761	
O&M Costs:	$826,671	*(for initial year of operation)*

These financial results include the costs associated with the gas collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime

(million ft^3 methane):	5,155
($MMTCO_2E$):	2.08E+00

Average Annual

(million ft^3 methane/yr):	344
($MMTCO_2E$/yr):	1.38E-01

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	2.33E-01
Average Annual ($MMTCO_2E$/yr):	1.55E-02

Landfill Characteristics

Open Year: 1994

Closure Year: 2014

Waste-In-Place at Closure (tons) 5,400,000

Average Waste Acceptance (tons/yr): 270,000

Average Depth of Landfill Waste (ft): 50

Area of LFG Wellfield to Supply Project (acres): 110

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	1,215	
Annual Average:	1,539	
Maximum:	1,813	
Collected During Project Lifetime (ft^3/min):		
Minimum:	1,033	
Annual Average:	1,308	
Maximum:	1,541	
Project Size:	Minimum	
Design Flow Rate for Project (ft^3/min):	1,033	
Utilized by Project (ft^3/min):		
Annual Average:	961	
LFG Collection Efficiency:	85%	

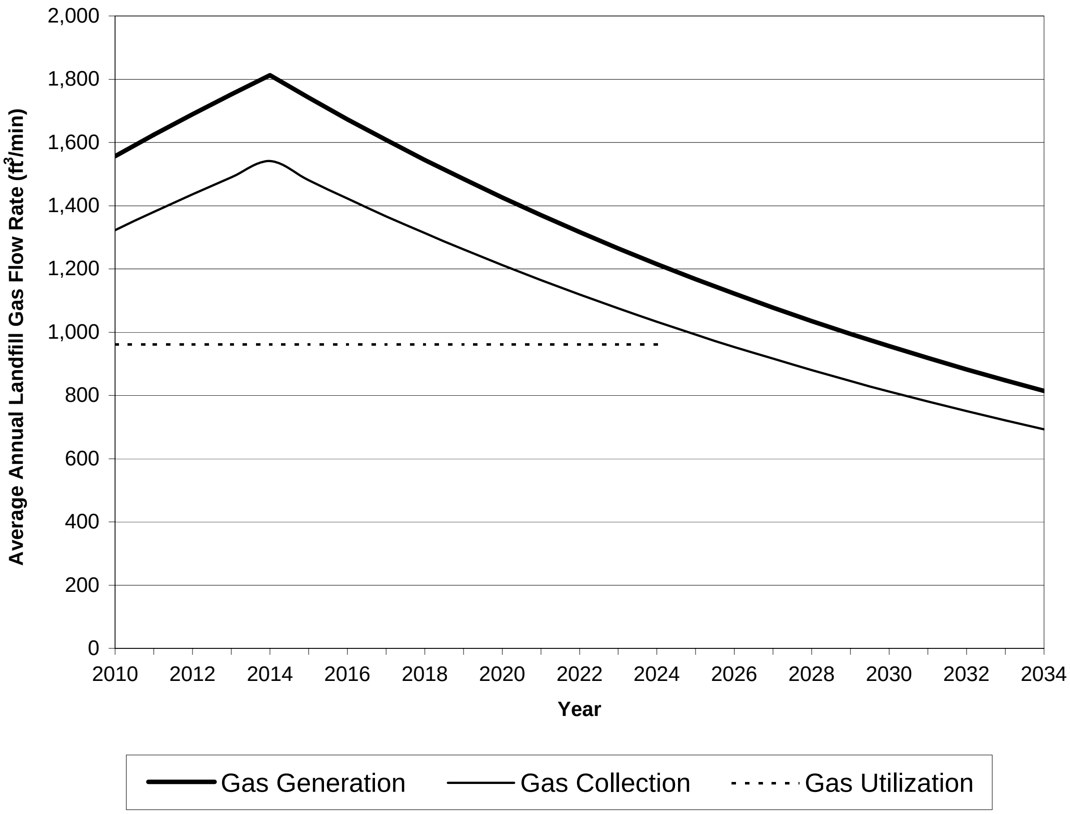
Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	8.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	35.0%	
Discount Rate:	10.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	Included	

Electricity Production and Sales Summary

Total Generation Capacity (kW):	2,787	
Average Generation (million kWh/yr):	20.890	*(during the life of the project)*
Initial Year Electricity Price ($/kWh):	0.06	

Landfill Gas Generation, Collection, and Utilization Curve



LANDFILL METHANE OUTREACH PROGRAM

Case Study ID: Electricity 3

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model
LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Private Finance at Break Even Electricity Price Including Costs for Gas Collection and Flare

LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Monday, December 15, 2008

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but can not be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Standard Reciprocating Engine-Generator Set	
Financial Results:		
Net Present Value:	$376	*(at year of construction)*
Internal Rate of Return:	10%	
Net Present Value Payback (yrs):	15	*(years after operation begins)*
Capital Costs:	$5,178,761	
O&M Costs:	$847,944	*(for initial year of operation)*

These financial results include the costs associated with the gas collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	5,155
($MMTCO_2E$):	2.08E+00
Average Annual	
(million ft^3 methane/yr):	344
($MMTCO_2E$/yr):	1.38E-01

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	2.25E-01
Average Annual ($MMTCO_2E$/yr):	1.50E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	5,400,000
Average Waste Acceptance (tons/yr):	270,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	110

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	1,215	
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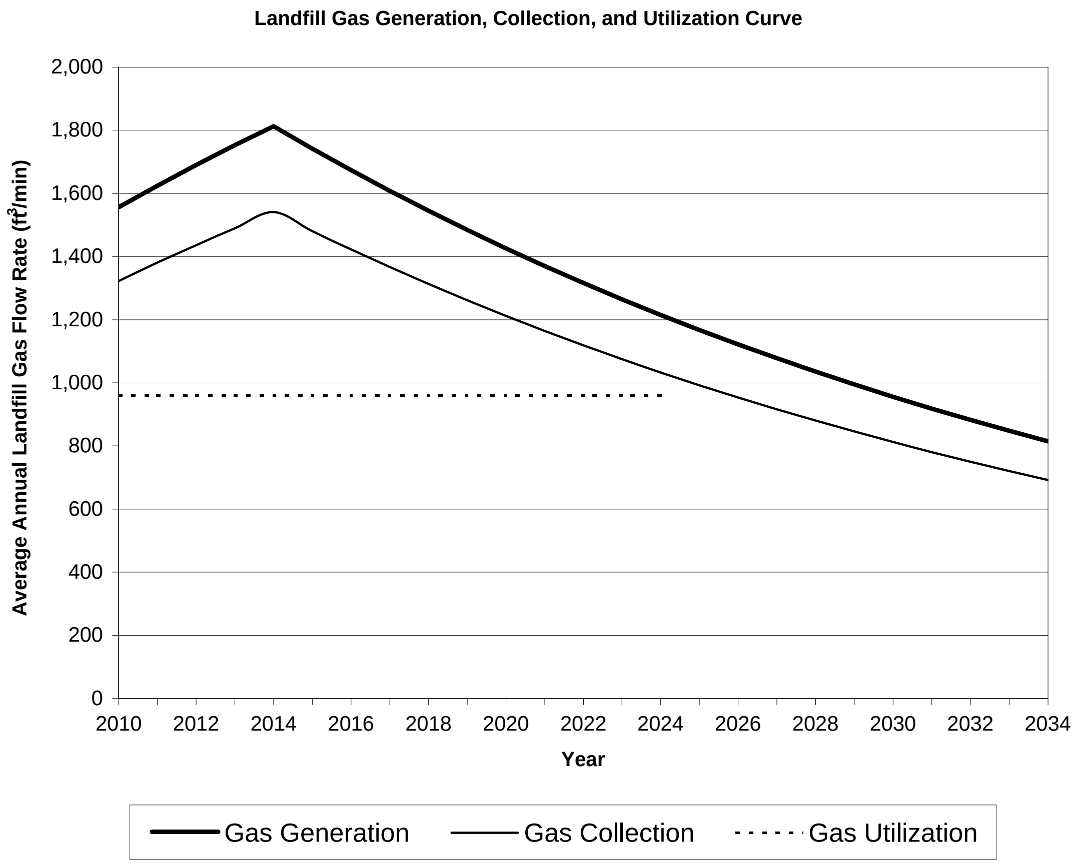
Collected During Project Lifetime (ft^3/min):		
Minimum:	1,033	
Annual Average:	1,308	
Maximum:	1,541	
Project Size:	Minimum	
Design Flow Rate for Project (ft^3/min):	1,033	
Utilized by Project (ft^3/min):		
Annual Average:	961	
LFG Collection Efficiency:	85%	

Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	8.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	35.0%	
Discount Rate:	10.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	Included	

Electricity Production and Sales Summary

Total Generation Capacity (kW):	2,787	
Average Generation (million kWh/yr):	20.890	*(during the life of the project)*
Price to Achieve Financial Goals ($/kWh):	0.0753	*(determined by Financial Goals Calculator results)*


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft3/min)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

LANDFILL METHANE OUTREACH PROGRAM

Case Study ID: Electricity 4

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Private Finance with CO_2 Credit
Including Costs of Gas Collection and Flare
LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Monday, December 15, 2008

Disclaimer:
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The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

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Summary Results

Project Start Year: 2010

Project End Year: 2024

Project Type: Standard Reciprocating Engine-Generator Set

Financial Results:

Net Present Value:	$1,364,007	*(at year of construction)*
Internal Rate of Return:	21%	
Net Present Value Payback (yrs):	9	*(years after operation begins)*
Capital Costs:	$5,178,761	
O&M Costs:	$826,671	*(for initial year of operation)*

These financial results include the costs associated with the gas collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime

(million ft^3 methane):	5,155
($MMTCO_2E$):	2.08E+00

Average Annual

(million ft^3 methane/yr):	344
($MMTCO_2E$/yr):	1.38E-01

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	2.33E-01
Average Annual ($MMTCO_2E$/yr):	1.55E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	5,400,000
Average Waste Acceptance (tons/yr):	270,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	110

Landfill Gas Generation, Collection, and Utilization

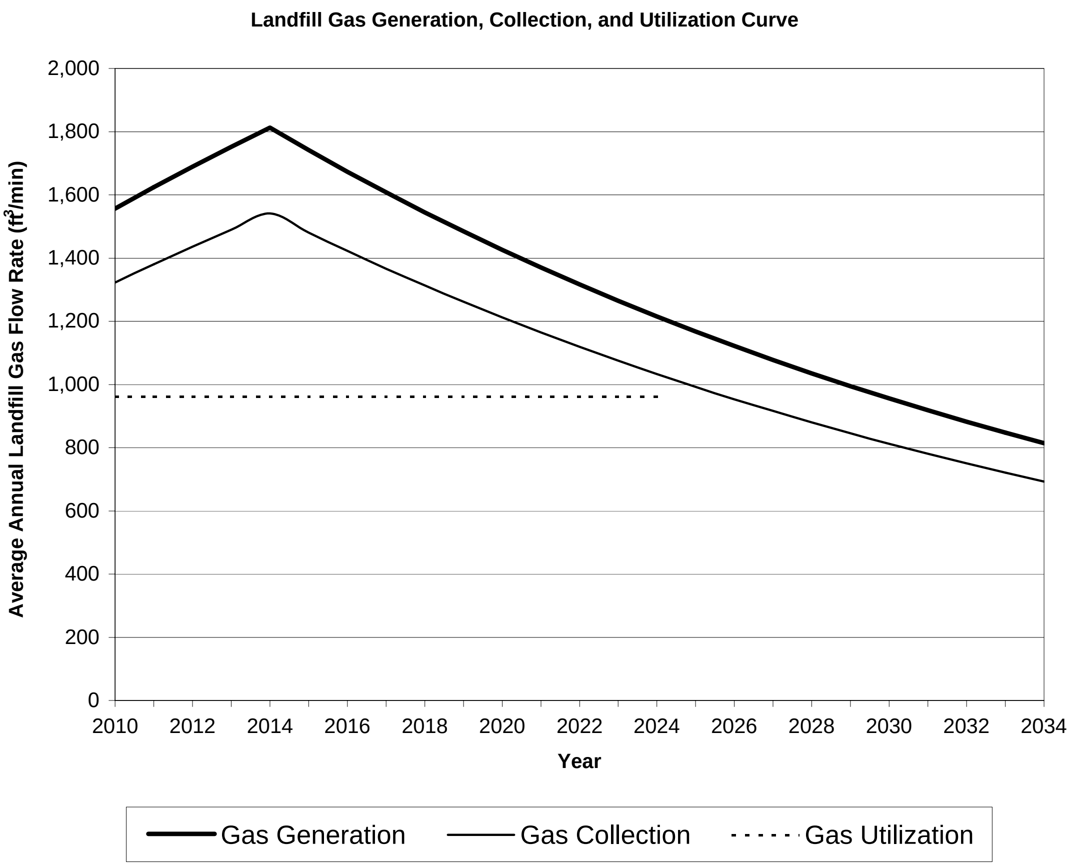
Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	1,215	
Annual Average:	1,539	
Maximum:	1,813	
Collected During Project Lifetime (ft^3/min):		
Minimum:	1,033	
Annual Average:	1,308	
Maximum:	1,541	
Project Size:	Minimum	
Design Flow Rate for Project (ft^3/min):	1,033	
Utilized by Project (ft^3/min):		
Annual Average:	961	
LFG Collection Efficiency:	85%	

Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	8.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	35.0%	
Discount Rate:	10.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	Included	
CO2 Emission Reduction Credit (\$/MTCO_2E):	\$4.00	

Electricity Production and Sales Summary

Total Generation Capacity (kW):	2,787	
Average Generation (million kWh/yr):	20.890	*(during the life of the project)*
Initial Year Electricity Price (\$/kWh):	0.06	


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft3/min)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

Case Study ID: Electricity 5

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Private Finance with Renewable Electricity Credit (REC)

LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Monday, December 15, 2008

Disclaimer:
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The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

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Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Standard Reciprocating Engine-Generator Set	
Financial Results:		
Net Present Value:	$3,318,320	*(at year of construction)*
Internal Rate of Return:	47%	
Net Present Value Payback (yrs):	3	*(years after operation begins)*
Capital Costs:	$3,555,156	
O&M Costs:	$470,328	*(for initial year of operation)*

These financial results DO NOT include the costs associated with the LFG collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	5,155
($MMTCO_2E$):	2.08E+00
Average Annual	
(million ft^3 methane/yr):	344
($MMTCO_2E$/yr):	1.38E-01

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	2.33E-01
Average Annual ($MMTCO_2E$/yr):	1.55E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	5,400,000
Average Waste Acceptance (tons/yr):	270,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	110

Landfill Gas Generation, Collection, and Utilization

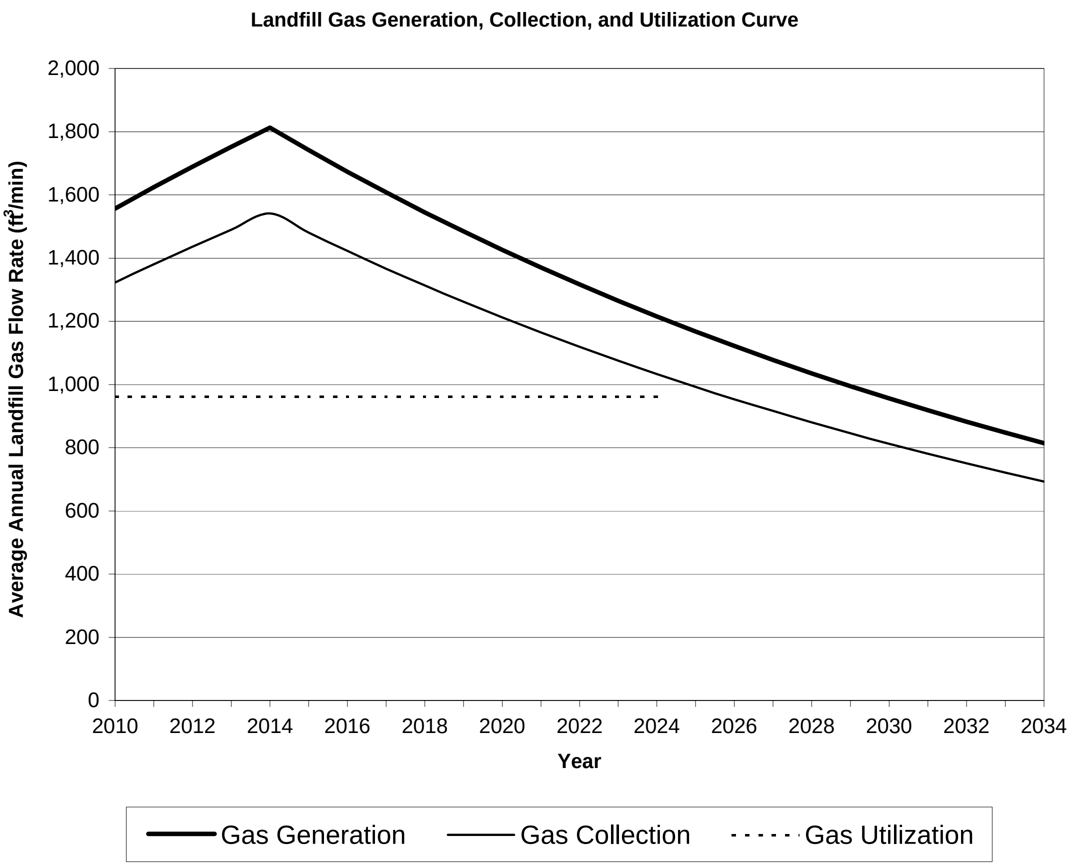
Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	1,215	
Annual Average:	1,539	
Maximum:	1,813	
Collected During Project Lifetime (ft^3/min):		
Minimum:	1,033	
Annual Average:	1,308	
Maximum:	1,541	
Project Size:	Minimum	
Design Flow Rate for Project (ft^3/min):	1,033	
Utilized by Project (ft^3/min):		
Annual Average:	961	
LFG Collection Efficiency:	85%	

Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	8.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	35.0%	
Discount Rate:	10.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	NOT Included	
Renewable Electricity Credit ($/kWh):	$0.020	

Electricity Production and Sales Summary

Total Generation Capacity (kW):	2,787	
Average Generation (million kWh/yr):	20.890	*(during the life of the project)*
Initial Year Electricity Price ($/kWh):	0.06	


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft3/min)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

Case Study ID: Electricity 6

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Municipal Budget Finance

LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Monday, December 15, 2008

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Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Standard Reciprocating Engine-Generator Set	
Financial Results:		
Net Present Value:	$4,590,440	*(at year of construction)*
Internal Rate of Return:	22%	
Net Present Value Payback (yrs):	6	*(years after operation begins)*
Capital Costs:	$3,555,156	
O&M Costs:	$470,328	*(for initial year of operation)*

These financial results DO NOT include the costs associated with the LFG collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	5,155
($MMTCO_2E$):	2.08E+00
Average Annual	
(million ft^3 methane/yr):	344
($MMTCO_2E$/yr):	1.38E-01

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	2.33E-01
Average Annual ($MMTCO_2E$/yr):	1.55E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	5,400,000
Average Waste Acceptance (tons/yr):	270,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	110

Landfill Gas Generation, Collection, and Utilization

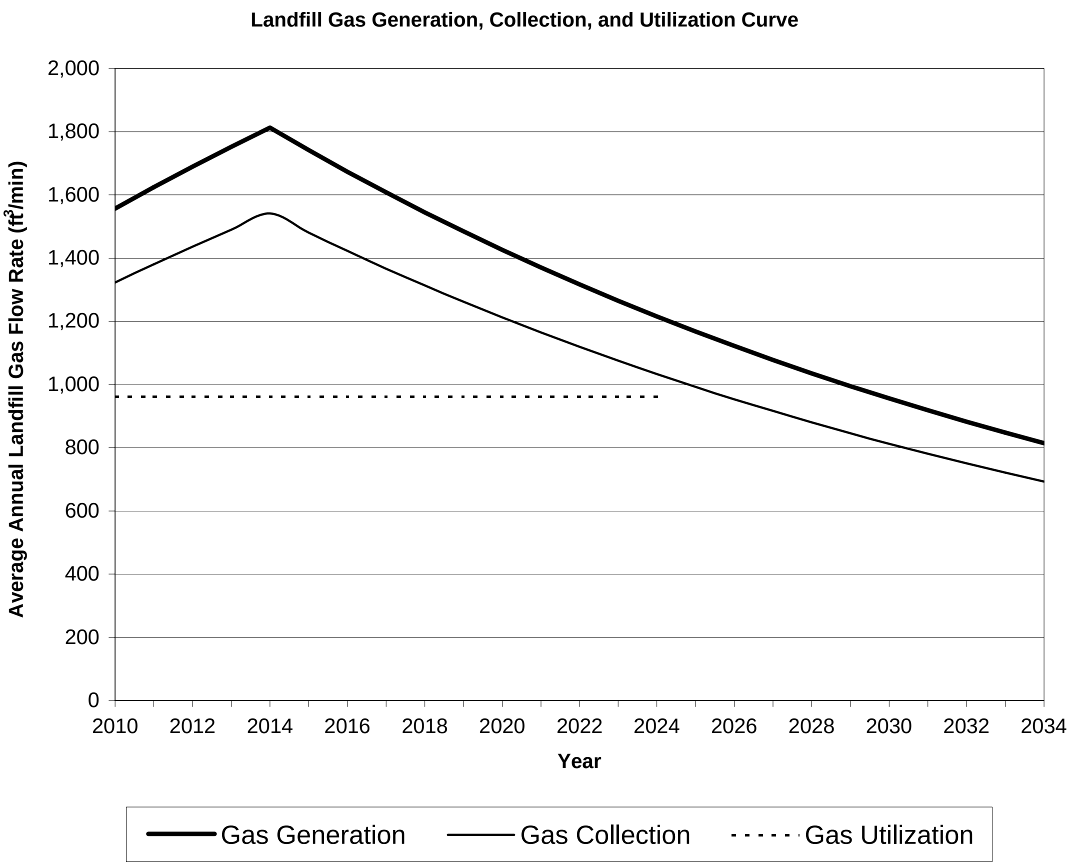
Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	1,215	
Annual Average:	1,539	
Maximum:	1,813	
Collected During Project Lifetime (ft^3/min):		
Minimum:	1,033	
Annual Average:	1,308	
Maximum:	1,541	
Project Size:	Minimum	
Design Flow Rate for Project (ft^3/min):	1,033	
Utilized by Project (ft^3/min):		
Annual Average:	961	
LFG Collection Efficiency:	85%	

Financial Assumptions

Loan Lifetime (years):	0	
Interest Rate:	0.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	0.0%	
Discount Rate:	6.0%	
Down Payment:	100.0%	
Collection and Flaring Costs:	NOT Included	

Electricity Production and Sales Summary

Total Generation Capacity (kW):	2,787	
Average Generation (million kWh/yr):	20.890	*(during the life of the project)*
Initial Year Electricity Price ($/kWh):	0.06	


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft3/min)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

Case Study ID: Electricity 7

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Municipal Bond Finance

LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Monday, December 15, 2008

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Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Standard Reciprocating Engine-Generator Set	
Financial Results:		
Net Present Value:	$4,429,452	*(at year of construction)*
Internal Rate of Return:	40%	
Net Present Value Payback (yrs):	4	*(years after operation begins)*
Capital Costs:	$3,555,156	
O&M Costs:	$470,328	*(for initial year of operation)*

These financial results DO NOT include the costs associated with the LFG collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	5,155
($MMTCO_2E$):	2.08E+00
Average Annual	
(million ft^3 methane/yr):	344
($MMTCO_2E$/yr):	1.38E-01

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	2.33E-01
Average Annual ($MMTCO_2E$/yr):	1.55E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	5,400,000
Average Waste Acceptance (tons/yr):	270,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	110

Landfill Gas Generation, Collection, and Utilization

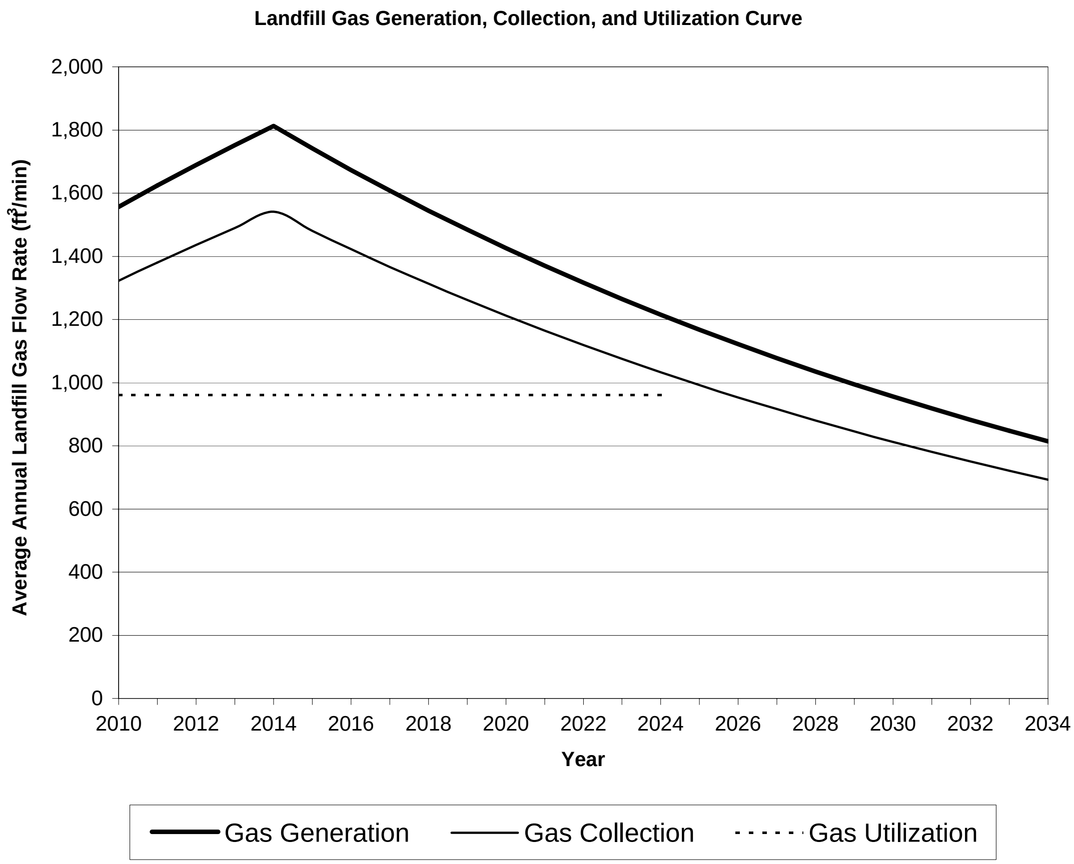
Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	1,215	
Annual Average:	1,539	
Maximum:	1,813	
Collected During Project Lifetime (ft^3/min):		
Minimum:	1,033	
Annual Average:	1,308	
Maximum:	1,541	
Project Size:	Minimum	
Design Flow Rate for Project (ft^3/min):	1,033	
Utilized by Project (ft^3/min):		
Annual Average:	961	
LFG Collection Efficiency:	85%	

Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	6.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	0.0%	
Discount Rate:	6.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	NOT Included	

Electricity Production and Sales Summary

Total Generation Capacity (kW):	2,787	
Average Generation (million kWh/yr):	20.890	*(during the life of the project)*
Initial Year Electricity Price ($/kWh):	0.06	


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft3/min)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

LANDFILL METHANE OUTREACH PROGRAM

Case Study ID: Electricity 8

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Municipal Budget Finance
Including Costs for Gas Collection and Flare
LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Monday, December 15, 2008

Disclaimer:
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Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Standard Reciprocating Engine-Generator Set	
Financial Results:		
Net Present Value:	($718,079)	*(at year of construction)*
Internal Rate of Return:	4%	
Net Present Value Payback (yrs):	None	*(years after operation begins)*
Capital Costs:	$5,178,761	
O&M Costs:	$826,671	*(for initial year of operation)*

These financial results include the costs associated with the gas collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	5,155
($MMTCO_2E$):	2.08E+00
Average Annual	
(million ft^3 methane/yr):	344
($MMTCO_2E$/yr):	1.38E-01

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	2.33E-01
Average Annual ($MMTCO_2E$/yr):	1.55E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	5,400,000
Average Waste Acceptance (tons/yr):	270,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	110

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	1,215	
Annual Average:	1,539	
Maximum:	1,813	
Collected During Project Lifetime (ft^3/min):		
Minimum:	1,033	
Annual Average:	1,308	
Maximum:	1,541	
Project Size:	Minimum	
Design Flow Rate for Project (ft^3/min):	1,033	
Utilized by Project (ft^3/min):		
Annual Average:	961	
LFG Collection Efficiency:	85%	

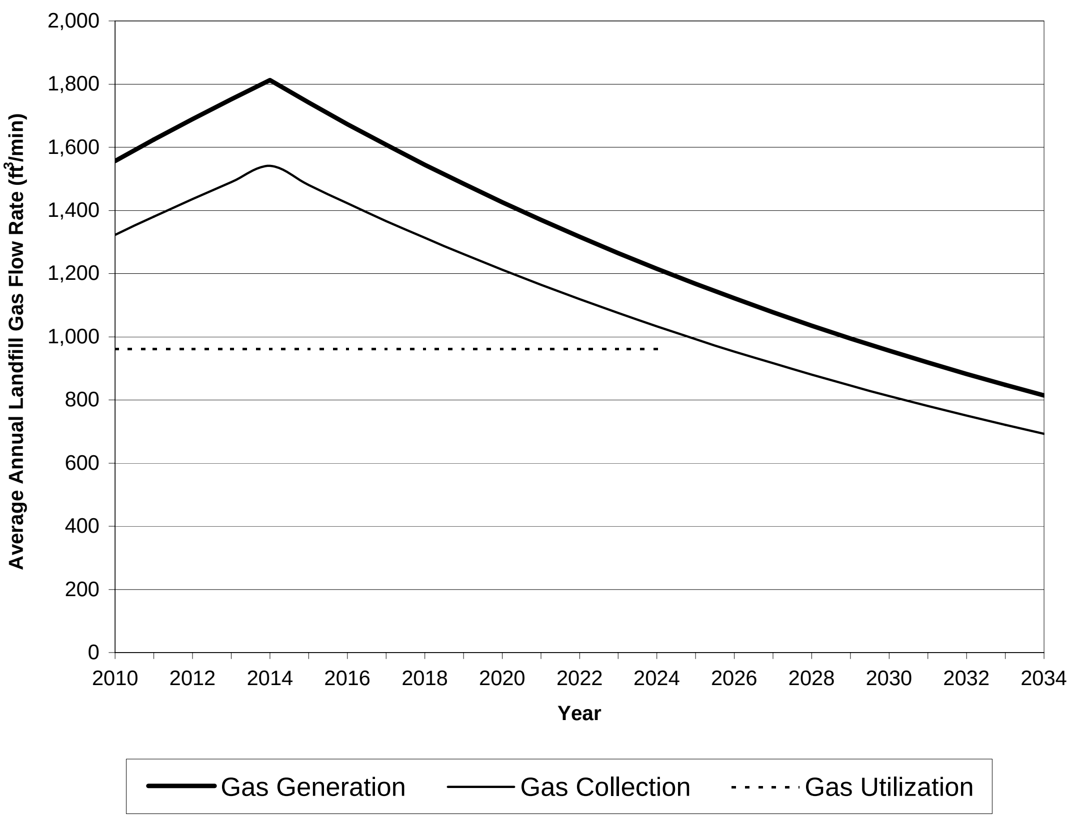
Financial Assumptions

Loan Lifetime (years):	0	
Interest Rate:	0.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	0.0%	
Discount Rate:	6.0%	
Down Payment:	100.0%	
Collection and Flaring Costs:	Included	

Electricity Production and Sales Summary

Total Generation Capacity (kW):	2,787	
Average Generation (million kWh/yr):	20.890	*(during the life of the project)*
Initial Year Electricity Price ($/kWh):	0.06	

Landfill Gas Generation, Collection, and Utilization Curve



LANDFILL METHANE OUTREACH PROGRAM

Case Study ID: Electricity 9

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model
LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Municipal Bond Finance
Including Costs for Gas Collection and Flare
LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Monday, December 15, 2008

Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Standard Reciprocating Engine-Generator Set	
Financial Results:		
Net Present Value:	($952,589)	*(at year of construction)*
Internal Rate of Return:	1%	
Net Present Value Payback (yrs):	None	*(years after operation begins)*
Capital Costs:	$5,178,761	
O&M Costs:	$826,671	*(for initial year of operation)*

These financial results include the costs associated with the gas collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	5,155
($MMTCO_2E$):	2.08E+00
Average Annual	
(million ft^3 methane/yr):	344
($MMTCO_2E$/yr):	1.38E-01

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	2.33E-01
Average Annual ($MMTCO_2E$/yr):	1.55E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	5,400,000
Average Waste Acceptance (tons/yr):	270,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	110

<u>Landfill Gas Generation, Collection, and Utilization</u>

Modeling Parameters for First-Order Decay Equation:

Methane Generation Rate, k (1/yr):	0.040
Methane Generation Capacity, L_o (ft^3/ton):	3,204
Methane Content of LFG:	50%

Generated During Project Lifetime (ft^3/min):

Minimum:	1,215
Annual Average:	1,539
Maximum:	1,813

Collected During Project Lifetime (ft^3/min):

Minimum:	1,033
Annual Average:	1,308
Maximum:	1,541

Project Size: Minimum

Design Flow Rate for Project (ft^3/min): 1,033

Utilized by Project (ft^3/min):

Annual Average: 961

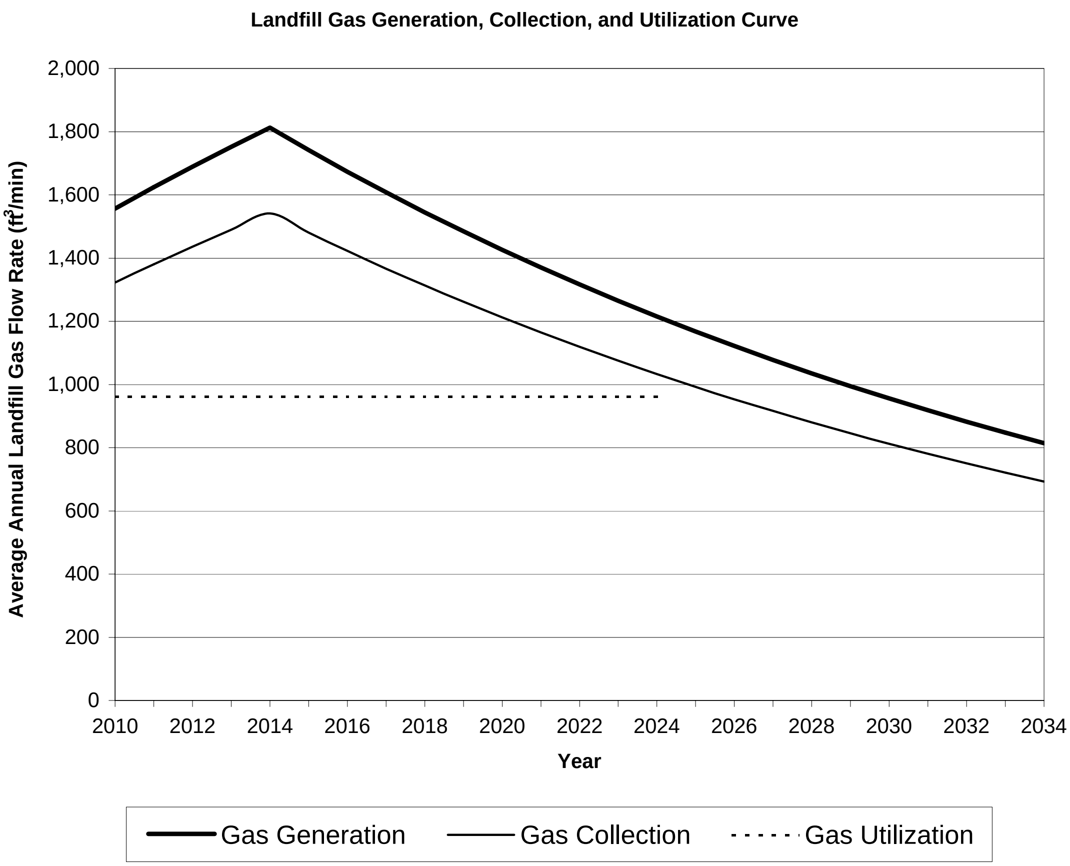
LFG Collection Efficiency: 85%

<u>Financial Assumptions</u>

Loan Lifetime (years):	10	
Interest Rate:	6.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	0.0%	
Discount Rate:	6.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	Included	

<u>Electricity Production and Sales Summary</u>

Total Generation Capacity (kW):	2,787	
Average Generation (million kWh/yr):	20.890	*(during the life of the project)*
Initial Year Electricity Price ($/kWh):	0.06	


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft3/min)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

Case Study ID: Electricity 10

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Municipal Bond Finance at Break Even Electricity Price Including Costs for Gas Collection and Flare

LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Monday, December 15, 2008

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but can not be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Standard Reciprocating Engine-Generator Set	
Financial Results:		
Net Present Value:	$852	*(at year of construction)*
Internal Rate of Return:	6%	
Net Present Value Payback (yrs):	15	*(years after operation begins)*
Capital Costs:	$5,178,761	
O&M Costs:	$833,248	*(for initial year of operation)*

These financial results include the costs associated with the gas collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	5,155
($MMTCO_2E$):	2.08E+00
Average Annual	
(million ft^3 methane/yr):	344
($MMTCO_2E$/yr):	1.38E-01

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	2.25E-01
Average Annual ($MMTCO_2E$/yr):	1.50E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	5,400,000
Average Waste Acceptance (tons/yr):	270,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	110

Landfill Gas Generation, Collection, and Utilization

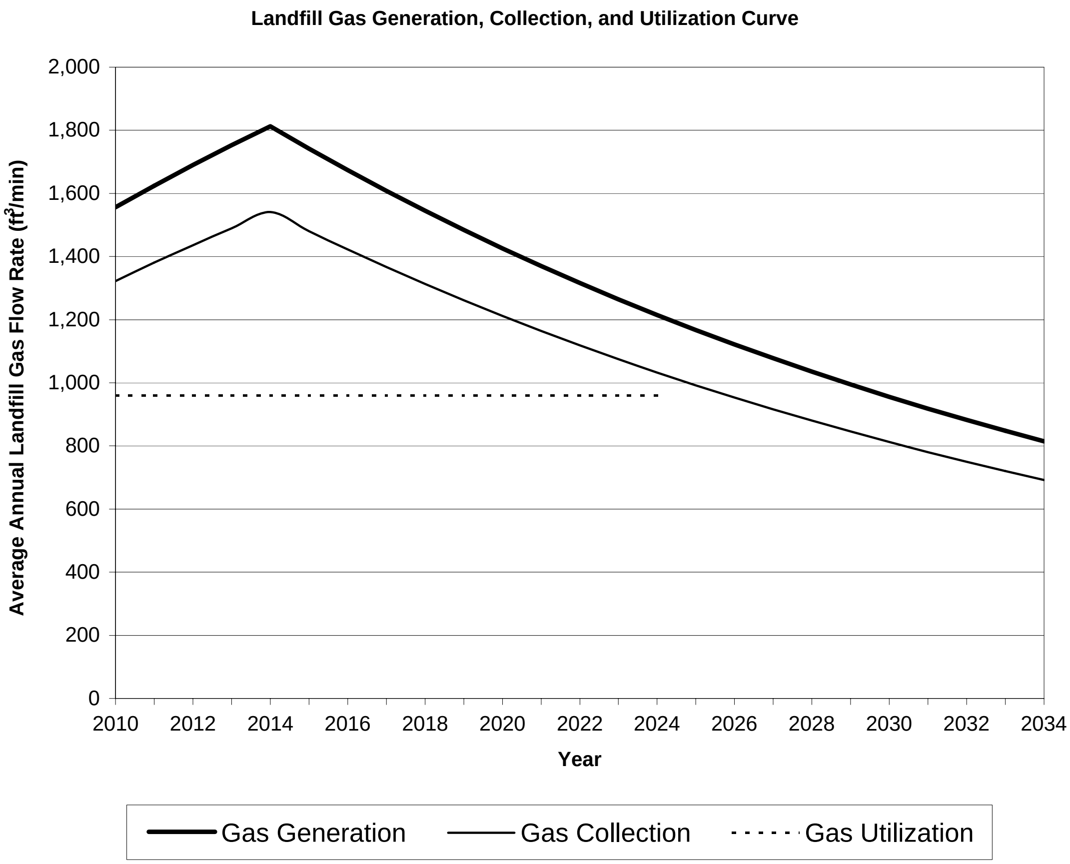
Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	1,215	
Annual Average:	1,539	
Maximum:	1,813	
Collected During Project Lifetime (ft^3/min):		
Minimum:	1,033	
Annual Average:	1,308	
Maximum:	1,541	
Project Size:	Minimum	
Design Flow Rate for Project (ft^3/min):	1,033	
Utilized by Project (ft^3/min):		
Annual Average:	961	
LFG Collection Efficiency:	85%	

Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	6.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	0.0%	
Discount Rate:	6.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	Included	

Electricity Production and Sales Summary

Total Generation Capacity (kW):	2,787	
Average Generation (million kWh/yr):	20.890	*(during the life of the project)*
Price to Achieve Financial Goals ($/kWh):	0.06473	*(determined by Financial Goals Calculator results)*


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft3/min)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

Appendix 4-B. Direct-Use Case Studies

The following case studies, obtained by running LMOP's LFGcost economic assessment tool, are example preliminary economic assessments for a direct-use (e.g., boiler) landfill gas (LFG) energy project. The first case, named "Direct Use 1" is a privately funded project at a landfill that already has an LFG collection and flaring system in place and requires 5 miles of pipeline to deliver the LFG to the end user. "Direct Use 2," a similar case, is a landfill that does not have an LFG collection and flaring system and must include collection system and flare costs in the economic assessment. Several other cases, including projects with 10-mile pipelines and projects that use municipal funding, are also included. The summary table below describes each case. The following pages present the actual output from LFGcost-Web.

Privately Developed Projects

Case Study Name	Project Description	Financing and Revenue Elements	Financial Results Summary
Direct Use 1	• Direct-use project with 5-mile pipeline (includes condensate management) • No collection and flaring system required	• 20% down payment, 80% financed • 8% interest rate • $8/MMBtu (default) LFG price	Capital cost: $1,683,253 O&M cost: $134,456 NPV: $7,362,931 IRR: 191% NPV payback (years): 1
Direct Use 2	• Direct-use project with 5-mile pipeline (includes condensate management) • LFG collection and flaring system required	• 20% down payment, 80% financed • 8% interest rate • $8/MMBtu (default) LFG price	Capital cost: $2,915,398 O&M cost: $411,516 NPV: $5,104,484 IRR: 82% NPV payback (years): 2
Direct Use 3	• Direct-use project with 10-mile pipeline (includes condensate management) • No collection and flaring system required	• 20% down payment, 80% financed • 8% interest rate • $8/MMBtu (default) LFG price	Capital cost: $3,098,471 O&M cost: $134,456 NPV: $6,401,960 IRR: 94% NPV payback (years): 2
Direct Use 4	• Direct-use project with 10-mile pipeline (includes condensate management) • LFG collection and flaring system required	• 20% down payment, 80% financed • 8% interest rate • $8/MMBtu (default) LFG price	Capital cost: $4,330,616 O&M cost: $411,516 NPV: $4,143,513 IRR: 48% NPV payback (years): 3

Municipality-Developed Projects

Case Study Name	Project Description	Financing and Revenue Elements	Financial Results Summary
Direct Use 5	• Direct-use project with 5-mile pipeline (includes condensate management) • No collection and flaring system required	• 100% down payment using municipal budget • 6% discount rate • $8/MMBtu (default) LFG price	Capital cost: $1,683,253 O&M cost: $134,456 NPV: $15,800,335 IRR: 106% NPV payback (years): 2
Direct Use 6	• Direct-use project with 5-mile pipeline (includes condensate management) • No collection and flaring system required	• 20% down payment, 80% bond-financed • 6% interest rate, 6% discount rate • $8/MMBtu (default) LFG price	Capital cost: $1,683,253 O&M cost: $134,456 NPV: $15,724,112 IRR: 304% NPV payback (years): 1
Direct Use 7	• Direct-use project with 5-mile pipeline (includes condensate management) • LFG collection and flaring system required	• 100% down payment using municipal budget • 6% discount rate • $8/MMBtu (default) LFG price	Capital cost: $2,915,398 O&M cost: $411,516 NPV: $11,704,935 IRR: 53% NPV payback (years): 3
Direct Use 8	• Direct-use project with 5-mile pipeline (includes condensate management) • LFG collection and flaring system required	• 20% down payment, 80% bond-financed • 6% interest rate, 6% discount rate • $8/MMBtu (default) LFG price	Capital cost: $2,915,398 O&M cost: $411,516 NPV: $11,572,917 IRR: 131% NPV payback (years): 1

IRR: internal rate of return

MMBtu = million British thermal units

NPV = net present value

O&M = operation and maintenance

Case Study ID: Direct Use 1

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Private Finance

LFGE Project Type: Direct Use
5-Mile Pipeline

Date: Monday, December 15, 2008

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but can not be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Project Start Year: 2010

Project End Year: 2024

Project Type: Direct Use

Financial Results:

Net Present Value:	$7,362,931	*(at year of construction)*
Internal Rate of Return:	191%	
Net Present Value Payback (yrs):	1	*(years after operation begins)*
Capital Costs:	$1,683,253	
O&M Costs:	$134,456	*(for initial year of operation)*

These financial results DO NOT include the costs associated with the LFG collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	3,819
($MMTCO_2E$):	1.54E+00
Average Annual	
(million ft^3 methane/yr):	255
($MMTCO_2E$/yr):	1.03E-01

Benefits from Avoided Direct Use of Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	1.75E-01
Average Annual ($MMTCO_2E$/yr):	1.17E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	4,000,000
Average Waste Acceptance (tons/yr):	200,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	80

Landfill Gas Generation, Collection, and Utilization

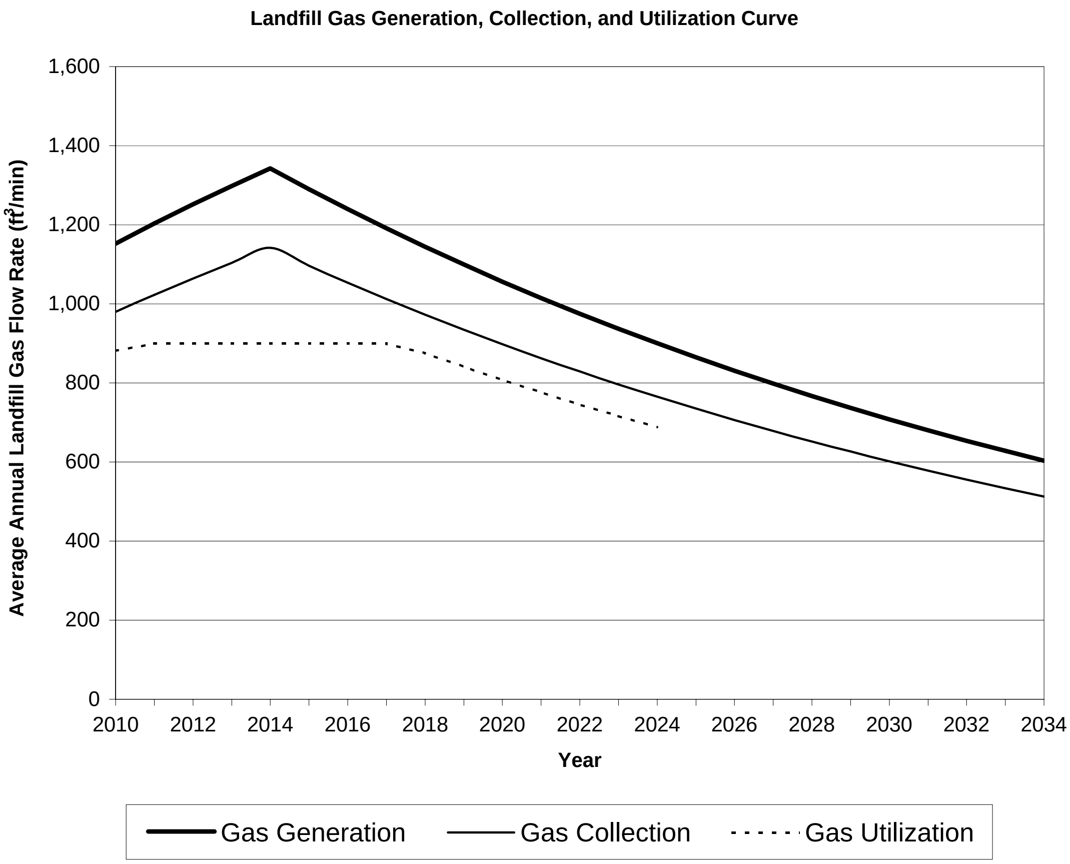
Modeling Parameters for First-Order Decay Equation:	
Methane Generation Rate, k (1/yr):	0.040
Methane Generation Capacity, L_o (ft^3/ton):	3,204
Methane Content of LFG:	50%
Generated During Project Lifetime (ft^3/min):	
Minimum:	900
Annual Average:	1,140
Maximum:	1,343
Collected During Project Lifetime (ft^3/min):	
Minimum:	765
Annual Average:	969
Maximum:	1,141
Project Size:	Defined by User
Design Flow Rate for Project (ft^3/min):	1,000
Utilized by Project (ft^3/min):	
Annual Average:	842
LFG Collection Efficiency:	85%

Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	8.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	35.0%	
Discount Rate:	10.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	NOT Included	

Direct Use Production and Sales Summary

Pipeline Length From Landfill to End User (mi):	5.0	
LFG Average Utilization (million Btu/yr):	223,995	*(during the life of the project)*
Initial Year LFG Price ($/million Btu):	8	


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft³/min)
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

LANDFILL METHANE OUTREACH PROGRAM

Case Study ID: Direct Use 2

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Private Finance
Including Costs for Gas Collection and Flare
LFGE Project Type: Direct Use
5-Mile Pipeline
Date: Monday, December 15, 2008

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but can not be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

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Direct Use 2

Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Direct Use	
Financial Results:		
Net Present Value:	$5,104,484	*(at year of construction)*
Internal Rate of Return:	82%	
Net Present Value Payback (yrs):	2	*(years after operation begins)*
Capital Costs:	$2,915,398	
O&M Costs:	$411,516	*(for initial year of operation)*

These financial results include the costs associated with the gas collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	3,819
($MMTCO_2E$):	1.54E+00
Average Annual	
(million ft^3 methane/yr):	255
($MMTCO_2E$/yr):	1.03E-01

Benefits from Avoided Direct Use of Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	1.75E-01
Average Annual ($MMTCO_2E$/yr):	1.17E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	4,000,000
Average Waste Acceptance (tons/yr):	200,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	80

Landfill Gas Generation, Collection, and Utilization

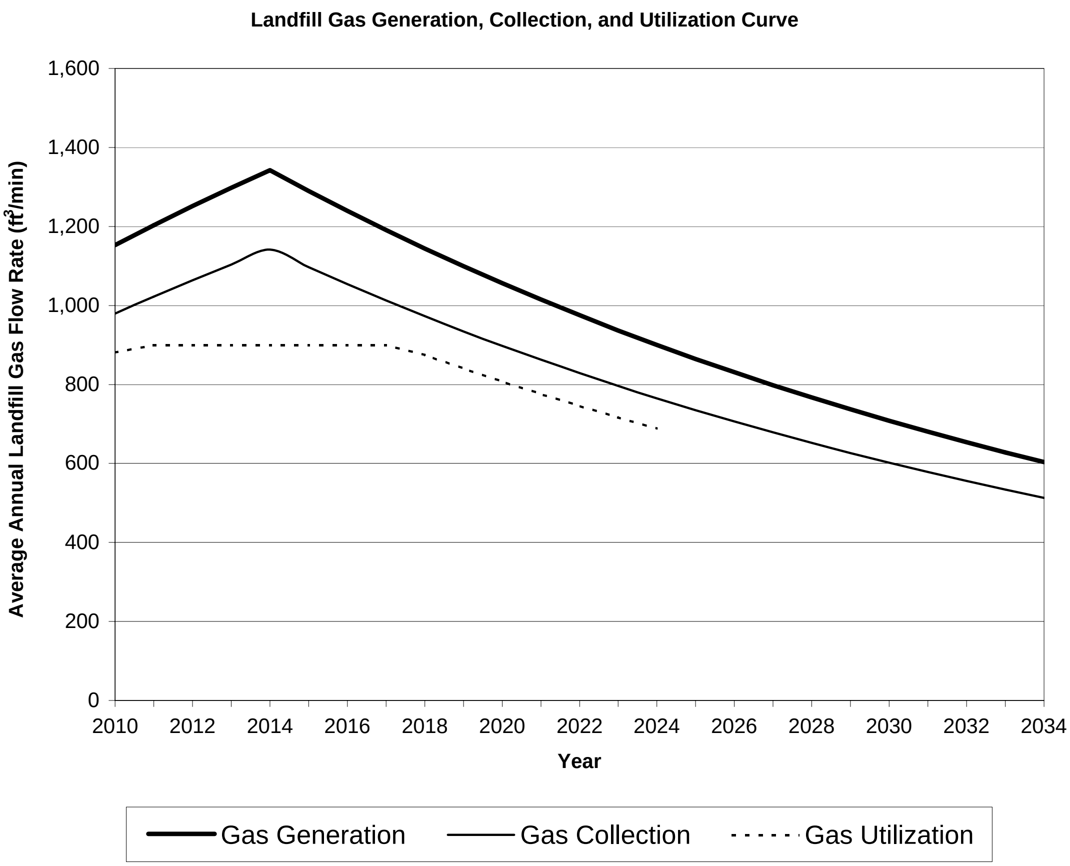
Modeling Parameters for First-Order Decay Equation:	
Methane Generation Rate, k (1/yr):	0.040
Methane Generation Capacity, L_o (ft^3/ton):	3,204
Methane Content of LFG:	50%
Generated During Project Lifetime (ft^3/min):	
Minimum:	900
Annual Average:	1,140
Maximum:	1,343
Collected During Project Lifetime (ft^3/min):	
Minimum:	765
Annual Average:	969
Maximum:	1,141
Project Size:	Defined by User
Design Flow Rate for Project (ft^3/min):	1,000
Utilized by Project (ft^3/min):	
Annual Average:	842
LFG Collection Efficiency:	85%

Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	8.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	35.0%	
Discount Rate:	10.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	Included	

Direct Use Production and Sales Summary

Pipeline Length From Landfill to End User (mi):	5.0	
LFG Average Utilization (million Btu/yr):	223,995	*(during the life of the project)*
Initial Year LFG Price ($/million Btu):	8	


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft3/min)
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

Case Study ID: Direct Use 3

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Private Finance

LFGE Project Type: Direct Use
10-Mile Pipeline

Date: Monday, December 15, 2008

Disclaimer:
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Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Direct Use	
Financial Results:		
Net Present Value:	$6,401,960	*(at year of construction)*
Internal Rate of Return:	94%	
Net Present Value Payback (yrs):	2	*(years after operation begins)*
Capital Costs:	$3,098,471	
O&M Costs:	$134,456	*(for initial year of operation)*

These financial results DO NOT include the costs associated with the LFG collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	3,819
($MMTCO_2E$):	1.54E+00
Average Annual	
(million ft^3 methane/yr):	255
($MMTCO_2E$/yr):	1.03E-01

Benefits from Avoided Direct Use of Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	1.75E-01
Average Annual ($MMTCO_2E$/yr):	1.17E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	4,000,000
Average Waste Acceptance (tons/yr):	200,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	80

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	900	
Annual Average:	1,140	
Maximum:	1,343	
Collected During Project Lifetime (ft^3/min):		
Minimum:	765	
Annual Average:	969	
Maximum:	1,141	
Project Size:	Defined by User	
Design Flow Rate for Project (ft^3/min):	1,000	
Utilized by Project (ft^3/min):		
Annual Average:	842	
LFG Collection Efficiency:	85%	

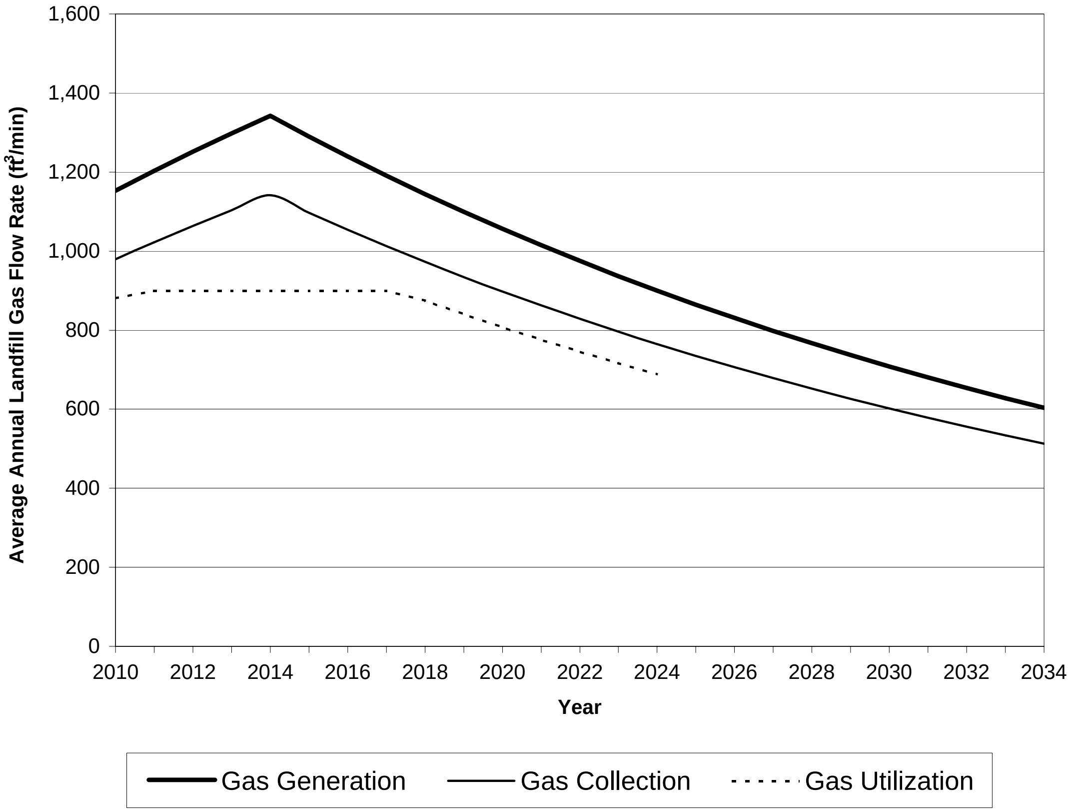
Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	8.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	35.0%	
Discount Rate:	10.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	NOT Included	

Direct Use Production and Sales Summary

Pipeline Length From Landfill to End User (mi):	10.0	
LFG Average Utilization (million Btu/yr):	223,995	*(during the life of the project)*
Initial Year LFG Price ($/million Btu):	8	

Landfill Gas Generation, Collection, and Utilization Curve



Case Study ID: Direct Use 4

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier:	Private Finance
	Including Costs for Gas Collection and Flare
LFGE Project Type:	Direct Use
	10-Mile Pipeline
Date:	Monday, December 15, 2008

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but can not be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Direct Use	
Financial Results:		
Net Present Value:	$4,143,513	*(at year of construction)*
Internal Rate of Return:	48%	
Net Present Value Payback (yrs):	3	*(years after operation begins)*
Capital Costs:	$4,330,616	
O&M Costs:	$411,516	*(for initial year of operation)*

These financial results include the costs associated with the gas collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	3,819
($MMTCO_2E$):	1.54E+00
Average Annual	
(million ft^3 methane/yr):	255
($MMTCO_2E$/yr):	1.03E-01

Benefits from Avoided Direct Use of Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	1.75E-01
Average Annual ($MMTCO_2E$/yr):	1.17E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	4,000,000
Average Waste Acceptance (tons/yr):	200,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	80

Landfill Gas Generation, Collection, and Utilization

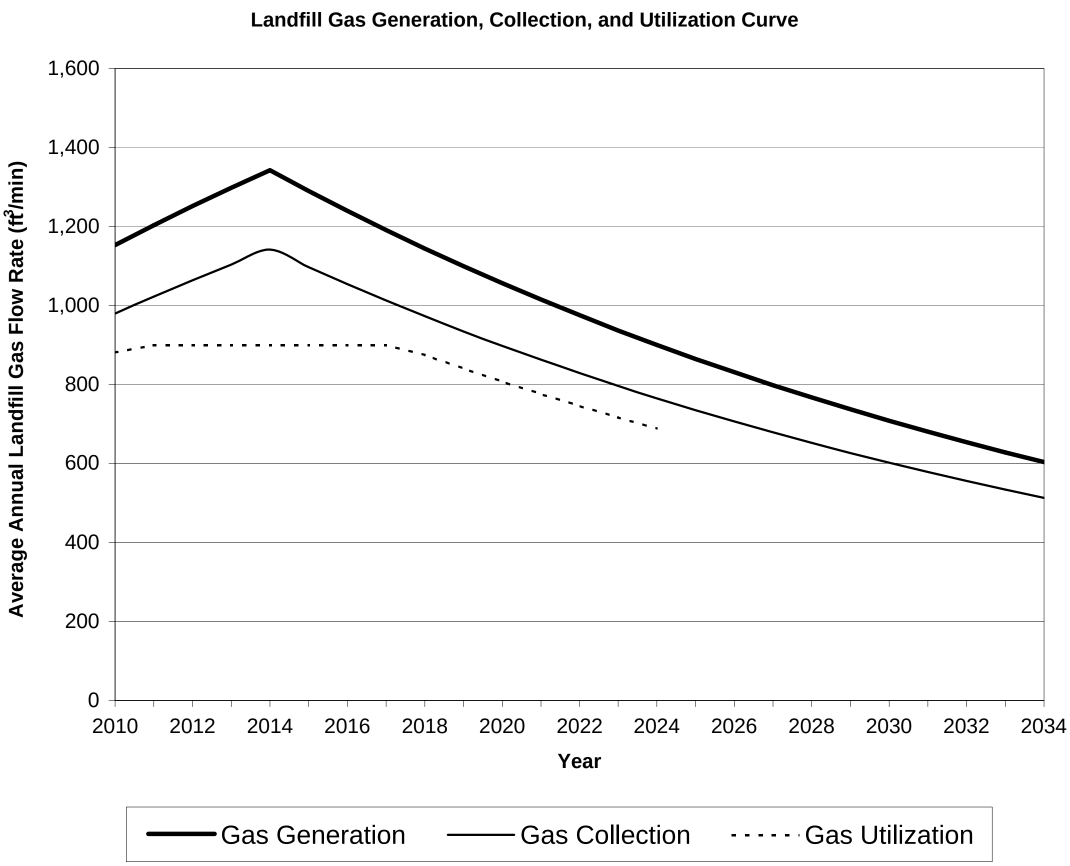
Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	900	
Annual Average:	1,140	
Maximum:	1,343	
Collected During Project Lifetime (ft^3/min):		
Minimum:	765	
Annual Average:	969	
Maximum:	1,141	
Project Size:	Defined by User	
Design Flow Rate for Project (ft^3/min):	1,000	
Utilized by Project (ft^3/min):		
Annual Average:	842	
LFG Collection Efficiency:	85%	

Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	8.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	35.0%	
Discount Rate:	10.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	Included	

Direct Use Production and Sales Summary

Pipeline Length From Landfill to End User (mi):	10.0	
LFG Average Utilization (million Btu/yr):	223,995	*(during the life of the project)*
Initial Year LFG Price ($/million Btu):	8	


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft3/min)
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

Case Study ID: Direct Use 5

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Municipal Budget Finance

LFGE Project Type: Direct Use
5-Mile Pipeline

Date: Monday, December 15, 2008

Disclaimer:
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The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

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Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Direct Use	
Financial Results:		
Net Present Value:	$15,800,335	*(at year of construction)*
Internal Rate of Return:	106%	
Net Present Value Payback (yrs):	2	*(years after operation begins)*
Capital Costs:	$1,683,253	
O&M Costs:	$134,456	*(for initial year of operation)*

These financial results DO NOT include the costs associated with the LFG collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	3,819
($MMTCO_2E$):	1.54E+00
Average Annual	
(million ft^3 methane/yr):	255
($MMTCO_2E$/yr):	1.03E-01

Benefits from Avoided Direct Use of Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	1.75E-01
Average Annual ($MMTCO_2E$/yr):	1.17E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	4,000,000
Average Waste Acceptance (tons/yr):	200,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	80

Landfill Gas Generation, Collection, and Utilization

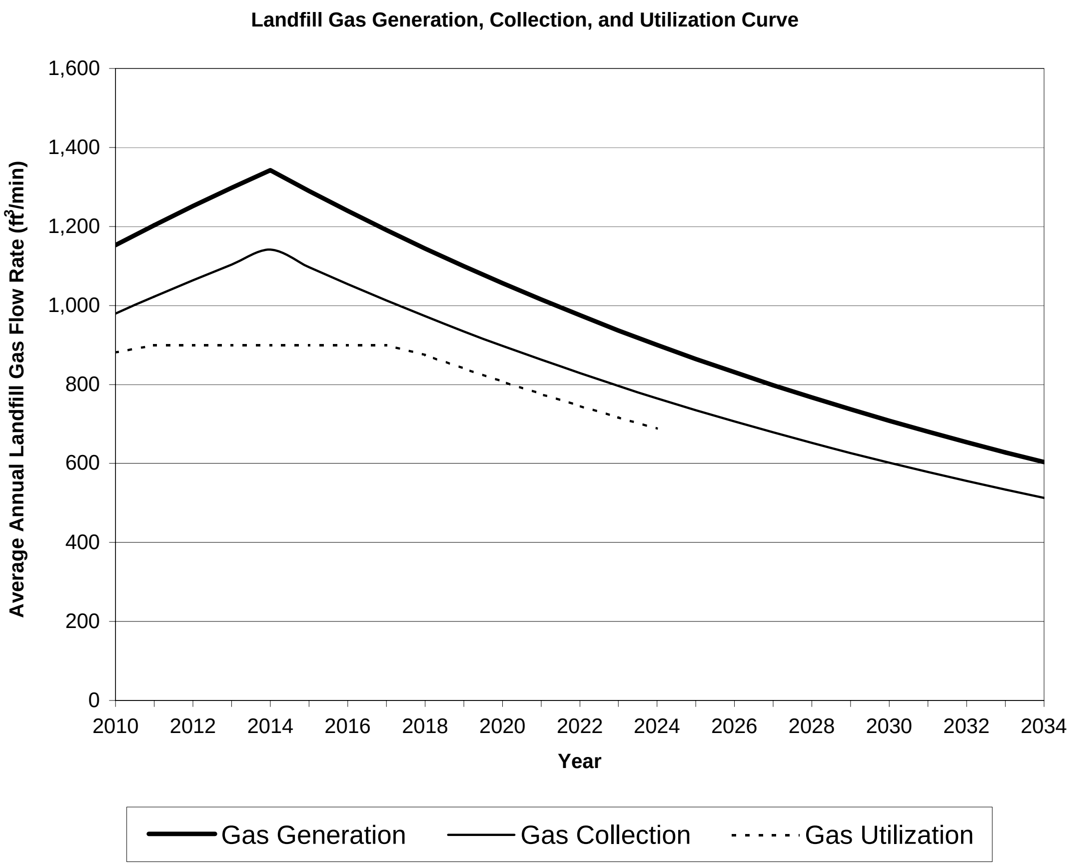
Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	900	
Annual Average:	1,140	
Maximum:	1,343	
Collected During Project Lifetime (ft^3/min):		
Minimum:	765	
Annual Average:	969	
Maximum:	1,141	
Project Size:	Defined by User	
Design Flow Rate for Project (ft^3/min):	1,000	
Utilized by Project (ft^3/min):		
Annual Average:	842	
LFG Collection Efficiency:	85%	

Financial Assumptions

Loan Lifetime (years):	0	
Interest Rate:	0.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	0.0%	
Discount Rate:	6.0%	
Down Payment:	100.0%	
Collection and Flaring Costs:	NOT Included	

Direct Use Production and Sales Summary

Pipeline Length From Landfill to End User (mi):	5.0	
LFG Average Utilization (million Btu/yr):	223,995	*(during the life of the project)*
Initial Year LFG Price ($/million Btu):	8	


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft3/min)
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

LANDFILL METHANE OUTREACH PROGRAM

Case Study ID: Direct Use 6

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Municipal Bond Finance

LFGE Project Type: Direct Use
5-Mile Pipeline

Date: Monday, December 15, 2008

Disclaimer:
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The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

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Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Direct Use	
Financial Results:		
Net Present Value:	$15,724,112	*(at year of construction)*
Internal Rate of Return:	304%	
Net Present Value Payback (yrs):	1	*(years after operation begins)*
Capital Costs:	$1,683,253	
O&M Costs:	$134,456	*(for initial year of operation)*

These financial results DO NOT include the costs associated with the LFG collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	3,819
($MMTCO_2E$):	1.54E+00
Average Annual	
(million ft^3 methane/yr):	255
($MMTCO_2E$/yr):	1.03E-01

Benefits from Avoided Direct Use of Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	1.75E-01
Average Annual ($MMTCO_2E$/yr):	1.17E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	4,000,000
Average Waste Acceptance (tons/yr):	200,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	80

Landfill Gas Generation, Collection, and Utilization

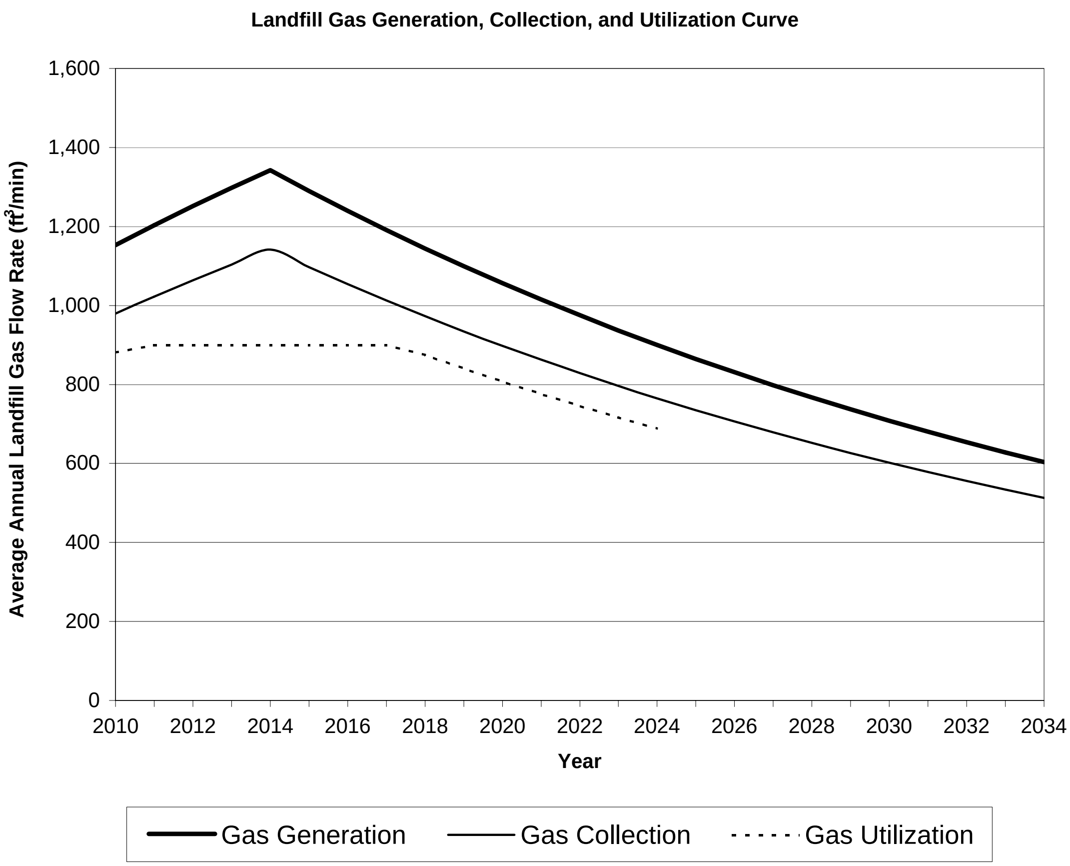
Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	900	
Annual Average:	1,140	
Maximum:	1,343	
Collected During Project Lifetime (ft^3/min):		
Minimum:	765	
Annual Average:	969	
Maximum:	1,141	
Project Size:	Defined by User	
Design Flow Rate for Project (ft^3/min):	1,000	
Utilized by Project (ft^3/min):		
Annual Average:	842	
LFG Collection Efficiency:	85%	

Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	6.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	0.0%	
Discount Rate:	6.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	NOT Included	

Direct Use Production and Sales Summary

Pipeline Length From Landfill to End User (mi):	5.0	
LFG Average Utilization (million Btu/yr):	223,995	*(during the life of the project)*
Initial Year LFG Price ($/million Btu):	8	


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft³/min)
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

Case Study ID: Direct Use 7

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Municipal Budget Finance
Including Costs for Gas Collection and Flare
LFGE Project Type: Direct Use
5-Mile Pipeline
Date: Monday, December 15, 2008

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Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Direct Use	
Financial Results:		
Net Present Value:	$11,704,935	*(at year of construction)*
Internal Rate of Return:	53%	
Net Present Value Payback (yrs):	3	*(years after operation begins)*
Capital Costs:	$2,915,398	
O&M Costs:	$411,516	*(for initial year of operation)*

These financial results include the costs associated with the gas collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	3,819
($MMTCO_2E$):	1.54E+00
Average Annual	
(million ft^3 methane/yr):	255
($MMTCO_2E$/yr):	1.03E-01

Benefits from Avoided Direct Use of Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	1.75E-01
Average Annual ($MMTCO_2E$/yr):	1.17E-02

Landfill Characteristics

Open Year:	1994
Closure Year:	2014
Waste-In-Place at Closure (tons)	4,000,000
Average Waste Acceptance (tons/yr):	200,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	80

Landfill Gas Generation, Collection, and Utilization

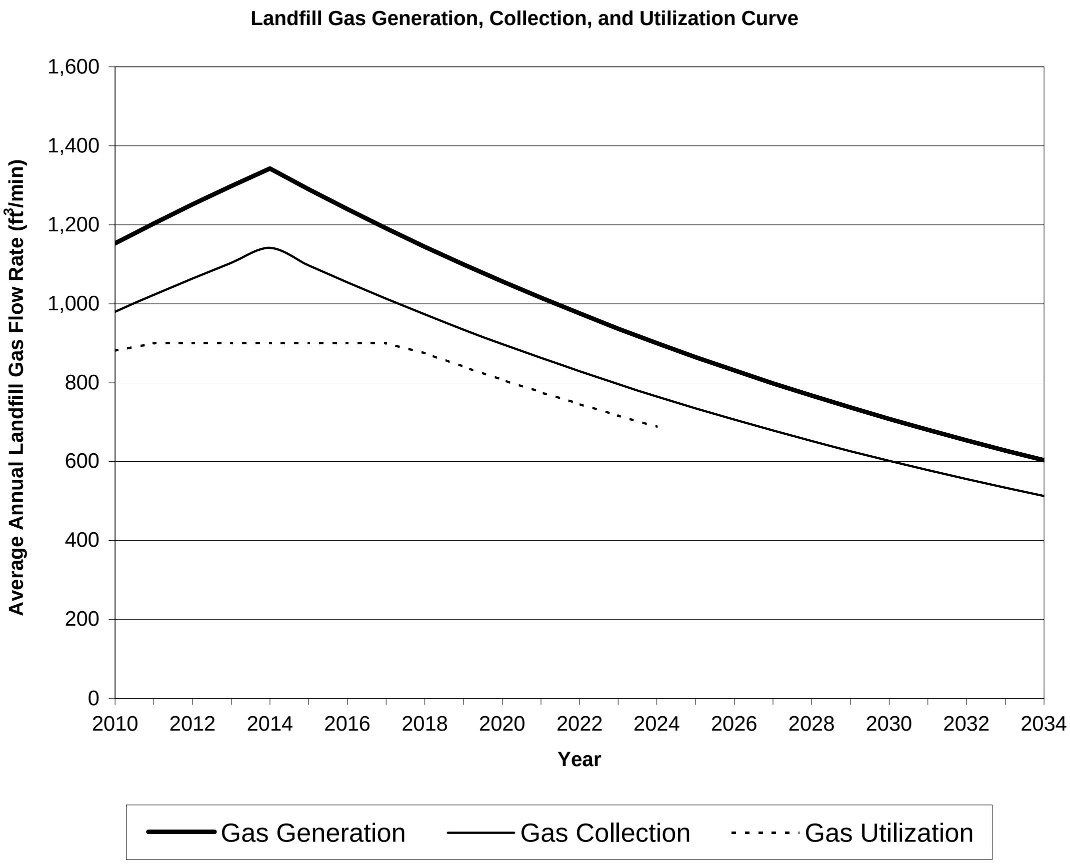
Modeling Parameters for First-Order Decay Equation:		
Methane Generation Rate, k (1/yr):	0.040	
Methane Generation Capacity, L_o (ft^3/ton):	3,204	
Methane Content of LFG:	50%	
Generated During Project Lifetime (ft^3/min):		
Minimum:	900	
Annual Average:	1,140	
Maximum:	1,343	
Collected During Project Lifetime (ft^3/min):		
Minimum:	765	
Annual Average:	969	
Maximum:	1,141	
Project Size:	Defined by User	
Design Flow Rate for Project (ft^3/min):	1,000	
Utilized by Project (ft^3/min):		
Annual Average:	842	
LFG Collection Efficiency:	85%	

Financial Assumptions

Loan Lifetime (years):	0	
Interest Rate:	0.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	0.0%	
Discount Rate:	6.0%	
Down Payment:	100.0%	
Collection and Flaring Costs:	Included	

Direct Use Production and Sales Summary

Pipeline Length From Landfill to End User (mi):	5.0	
LFG Average Utilization (million Btu/yr):	223,995	*(during the life of the project)*
Initial Year LFG Price ($/million Btu):	8	


Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft3/min)
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization

Case Study ID: Direct Use 8

U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 1.4

Summary Report

Landfill Name or Identifier: Municipal Bond Finance
Including Costs for Gas Collection and Flare

LFGE Project Type: Direct Use
5-Mile Pipeline

Date: Monday, December 15, 2008

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Summary Results

Project Start Year:	2010	
Project End Year:	2024	
Project Type:	Direct Use	
Financial Results:		
Net Present Value:	$11,572,917	*(at year of construction)*
Internal Rate of Return:	131%	
Net Present Value Payback (yrs):	1	*(years after operation begins)*
Capital Costs:	$2,915,398	
O&M Costs:	$411,516	*(for initial year of operation)*

These financial results include the costs associated with the gas collection and flaring system.

Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime	
(million ft^3 methane):	3,819
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Average Annual	
(million ft^3 methane/yr):	255
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Benefits from Avoided Direct Use of Fossil Fuels (during the life of the project):

Lifetime ($MMTCO_2E$):	1.75E-01
Average Annual ($MMTCO_2E$/yr):	1.17E-02

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Waste-In-Place at Closure (tons)	4,000,000
Average Waste Acceptance (tons/yr):	200,000
Average Depth of Landfill Waste (ft):	50
Area of LFG Wellfield to Supply Project (acres):	80

Landfill Gas Generation, Collection, and Utilization

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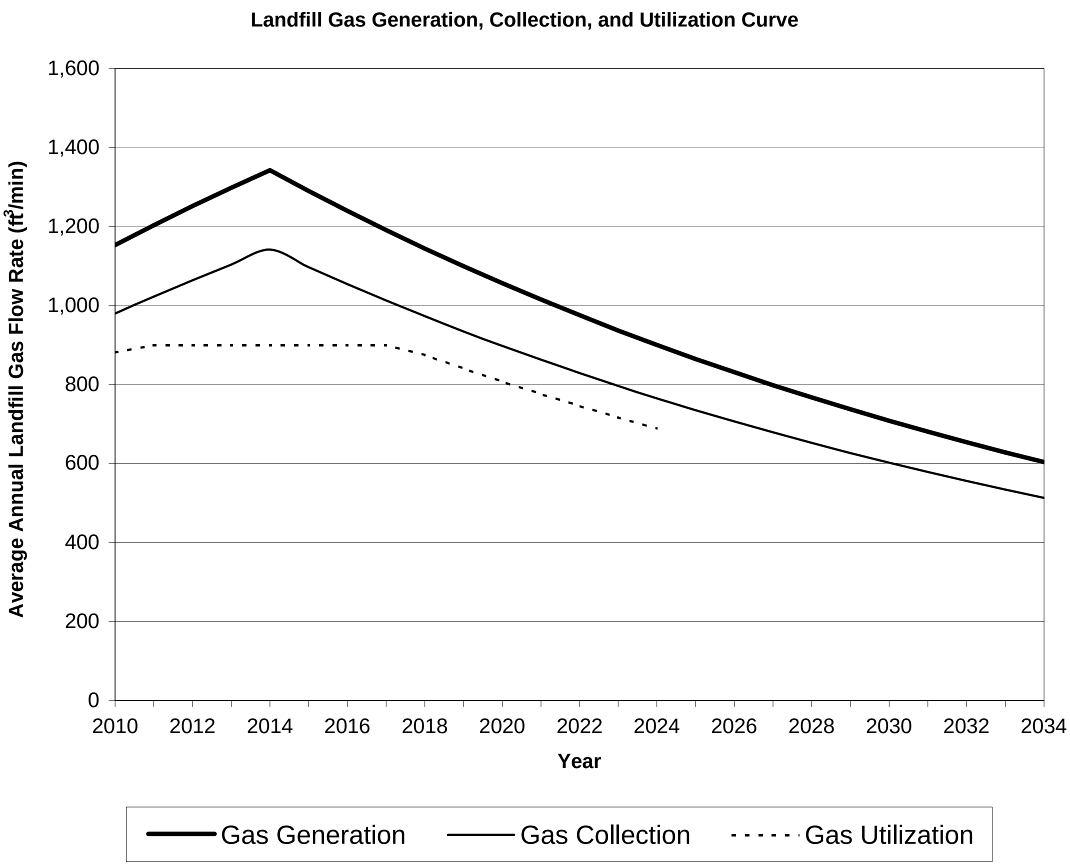
Maximum:	1,343	
Collected During Project Lifetime (ft^3/min):		
Minimum:	765	
Annual Average:	969	
Maximum:	1,141	
Project Size:	Defined by User	
Design Flow Rate for Project (ft^3/min):	1,000	
Utilized by Project (ft^3/min):		
Annual Average:	842	
LFG Collection Efficiency:	85%	

Financial Assumptions

Loan Lifetime (years):	10	
Interest Rate:	6.0%	
General Inflation Rate:	2.5%	*(applied to O&M costs)*
Equipment Inflation Rate:	1.0%	
Marginal Tax Rate:	0.0%	
Discount Rate:	6.0%	
Down Payment:	20.0%	
Collection and Flaring Costs:	Included	

Direct Use Production and Sales Summary

Pipeline Length From Landfill to End User (mi):	5.0	
LFG Average Utilization (million Btu/yr):	223,995	*(during the life of the project)*
Initial Year LFG Price ($/million Btu):	8	



Landfill Gas Generation, Collection, and Utilization Curve
Average Annual Landfill Gas Flow Rate (ft3/min)
1,600
1,400
1,200
1,000
800
600
400
200
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
Year
Gas Generation
Gas Collection
Gas Utilization