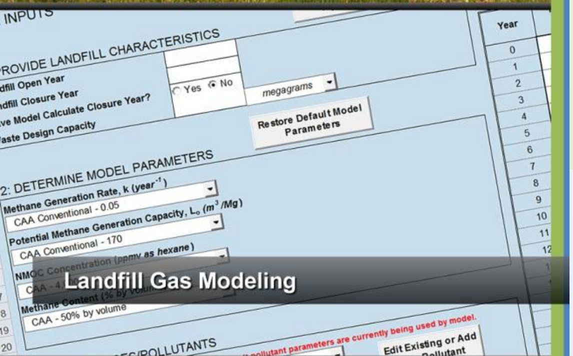

LANDFILL METHANE OUTREACH PROGRAM

LFG Energy Project Development Handbook

February 2015

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Units of Measure, Element Symbols, Constants and Variables

Btu	British thermal unit
cfd	Cubic feet per day
cfm	Cubic feet per minute
CH_4	Methane
CO_2e	Carbon dioxide equivalent
GGE	Gallons of gasoline equivalent
gpd	Gallons per day
k	Methane generation rate constant
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt hour
lb/hr	Pounds per hour
L_0	Potential methane generation capacity
m^3	Cubic meter
m^3/hr	Cubic meter per hour
m^3/Mg	Cubic meter per megagram
m^3/yr	Cubic meter per year
Mg	Megagram
M_i	Annual waste disposal rate
MMBtu	Million British thermal units
MMBtu/yr	Million British thermal units per year
mmscfd	Million standard cubic feet per day
$MMTCO_2e$	Million metric tons of carbon dioxide equivalent
MW	Megawatt
MWh	Megawatt hour
psi	Pounds per square inch
psig	Pound-force per square inch gauge
Q_{CH4}	Estimated methane generation flow rate
scfm	Standard cubic foot per minute
yr	Year

Abbreviations and Acronyms

ARB	Air Resources Board
ARRA	American Recovery and Reinvestment Act
CAA	Clean Air Act
C&D	Construction and Demolition
CFR	Code of Federal Regulations
CHP	Combined heat and power
CNG	Compressed natural gas
CREB	Clean Renewable Energy Bond
CWA	Clean Water Act
DSIRE	Database of State Incentives for Renewables and Efficiency
EG	Emission Guidelines
EPA	U.S. Environmental Protection Agency
EPC	Engineering, procurement and construction
ESA	Energy sales agreement
FLIGHT	Facility Level Information on GreenHouse gases Tool
GEC	Green Energy Center
GHG	Greenhouse gas
IOU	Investor-owned utilities
IRR	Internal rate of return
LandGEM	Landfill Gas Emissions Model
LFG	Landfill gas
LFGcost-Web	Landfill Gas Energy Cost Model
LMOP	The U.S. Environmental Protection Agency's Landfill Methane Outreach Program
LNG	Liquefied natural gas
MACT	Maximum achievable control technology
MSW	Municipal solid waste
NAAQS	National ambient air quality standards
NESHAP	National Emission Standards for Hazardous Air Pollutants
NMOC	Non-methane organic compounds
NPDES	National Pollutant Discharge Elimination System
NPV	Net present value
NSPS	New Source Performance Standards
NSR	New Source Review

NYMEX	New York Mercantile Exchange
O&M	Operation and maintenance
OPS	The U.S. Department of Transportation's Office of Pipeline Safety
OTC	Over-the-counter
PM	Project manager
POTW	Publicly owned treatment works
PPA	Power purchase agreement
PSA	Power sales agreement
PSD	Prevention of Significant Deterioration
RCRA	Resource Conservation and Recovery Act of 1976, as amended
REC	Renewable energy certificate
RFP	Request for proposal
RFS	Renewable Fuel Standard
RGGI	Regional Greenhouse Gas Initiative
RIN	Renewable Identification Number
RPG	Renewable Portfolio Goal
RPS	Renewable Portfolio Standard
RTO	Regional transmission operators
RVO	Renewable volume obligation
SCADA	Supervisory control and data acquisition
SIP	State Implementation Plan
SOQ	Statement of Qualifications
SSM	Startup, shutdown, and malfunction
SWANA	Solid Waste Association of North America
Uniform Act	Uniform Relocation Assistance and Real Property Acquisitions Act of 1970

Introduction

The *LFG Energy Project Development Handbook* provides an overview of landfill gas (LFG) energy project development guidance and presents the technological, economic and regulatory considerations that affect the feasibility and success of LFG energy projects. Landfill owners, energy service providers, end users, representatives of state agencies and local government, community members and other interested stakeholders will benefit from information provided in this handbook as they work together to develop successful LFG energy projects.

The handbook is organized into six chapters:

Chapter 1 – Landfill Gas Energy Basics
Chapter 2 – Landfill Gas Modeling
Chapter 3 – Project Technology Options
Chapter 4 – Project Economics and Financing
Chapter 5 – Landfill Gas Contracts and Permitting
Chapter 6 – Evaluating and Working with Project Partners

This handbook presents national statistics that reflect LMOP's Landfill and LFG Energy Project Database as of July 2014. Energy cost estimates presented in this handbook were calculated using Version 2.2 of the Landfill Gas Energy Cost Model (*LFGcost-Web*).

Using the Project Development Handbook

The handbook is designed to provide basic information that relates to all LFG energy projects—beginning with an explanation of what LFG is and the potential benefits of LFG energy projects—and present a more detailed overview of project-specific considerations.

The handbook discusses the status of LFG energy in the United States and presents the basic steps of developing an LFG energy project. Throughout the handbook, readers will find references to online resources that contain more comprehensive details, examples and helpful tools. Readers are encouraged to visit these resources to find information that may be relevant to individual projects and topics.

Disclaimer

The handbook is not an official guidance document. Instead, this document provides general information regarding LFG energy projects. It does not address all information, factors, applicable regulations or considerations that may be relevant or required. Any references to private entities, products or services are strictly for informational purposes and do not constitute an endorsement of that entity, product or service.

About LMOP

The Landfill Methane Outreach Program (LMOP) is a voluntary assistance and partnership program created by the U.S. Environmental Protection Agency (EPA) in 1994 to reduce methane emissions by encouraging the recovery and use of LFG as a renewable, green energy resource. LMOP has developed many publications and tools to assist those wishing to develop LFG energy projects or to promote LFG to various audiences. This handbook advances the purpose and mission of LMOP by providing the tools and necessary information to stakeholders for the development of successful LFG projects.

LMOP's website has become one of the main methods of providing LMOP Partners, others in the industry and the public with information about the latest LFG energy-related advances, opportunities, models and tools.

Visit **www.epa.gov/lmop** for complete details about LMOP.

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 using the LMOP Locator, a tool that can help a landfill owner, operator or project developer identify potential end users. Potential end users also can use the LMOP Locator to search for nearby landfills that are good candidates for project development.
- Making preliminary estimates of recoverable methane using LFG models such as the Landfill Gas Emissions Model (LandGEM) and site-specific information on landfill waste acceptance.
- Assisting with preliminary technical and economic feasibility assessments for LFG energy project options using tools such as *LFGcost-Web*.
- Helping to locate project partners through networking opportunities and by distributing Requests for Proposals (RFPs) through listserv messages.
- Answering technical questions and providing information to help overcome technical barriers to LFG energy projects. LMOP can also 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 outreach materials for project ribbon-cuttings and recognizing outstanding Partners and projects via LMOP's annual awards program.

Landfill and LFG Energy Project Database. LMOP's Landfill and LFG Energy Project database is the most comprehensive data repository in the country for information about LFG energy projects and landfills with potential for energy recovery. It is updated with information from LMOP Partners and other organizations in the industry. LMOP posts Excel files with landfill data on the website for viewing and downloading. 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. See www.epa.gov/lmop/projects-candidates/.

Frequently Asked Questions. LMOP's website provides answers to frequently asked questions about the program itself, about LFG energy projects in general, and about how LFG affects public health, safety and the environment. See www.epa.gov/lmop/faq/.

1. Landfill Gas Energy Basics

Harnessing the power of LFG energy provides environmental and economic benefits to landfills, energy users and the community. Working together, landfill owners, energy service providers, businesses, state agencies, local governments, communities and other stakeholders can develop successful LFG energy projects that:

- Reduce emissions of greenhouse gases (GHG) that contribute to global climate change
- Offset the use of non-renewable resources
- Help improve local air quality
- Provide revenue for landfills
- Reduce energy costs for users of LFG energy
- Create jobs and promote investment in local businesses

> The EPA Landfill Methane Outreach Program encourages and facilitates development of environmentally and economically sound LFG energy projects by partnering with stakeholders and providing a variety of information, tools and services.

This chapter describes the source and characteristics of LFG and presents basic information about the collection, treatment and use of LFG in energy recovery systems. This chapter also includes a discussion of the status of LFG energy in the United States, a review of the benefits of LFG energy projects and a summary of the current federal regulatory framework. Finally, general steps to LFG energy project development are introduced.

1.1 What Is LFG?

> Landfills are the third largest human-caused source of methane in the United States, accounting for approximately 18.2 percent of U.S. methane emissions in 2012.[1]

LFG is a natural byproduct of the decomposition of organic material in anaerobic (without oxygen) conditions. LFG contains roughly 50 to 55 percent methane and 45 to 50 percent carbon dioxide, with less than 1 percent non-methane organic compounds and trace amounts of inorganic compounds. Methane is a potent greenhouse (heat trapping) gas with a global warming potential that is 25 times greater than carbon dioxide.[1]

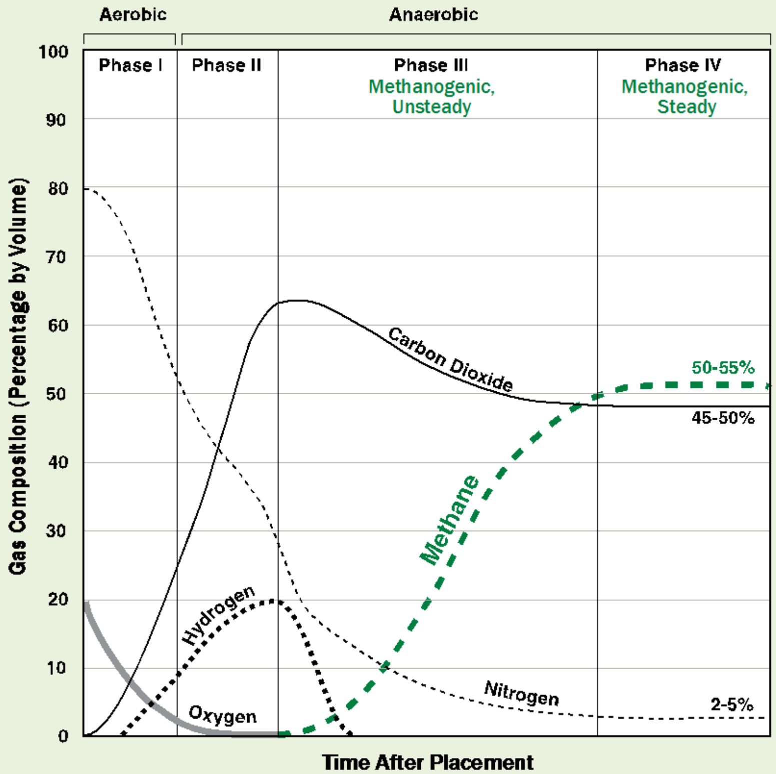
When municipal solid waste (MSW) is first deposited in a landfill, it undergoes an aerobic (with oxygen) decomposition stage when little methane is generated. Then, typically within less than 1 year, anaerobic conditions are established and methane-producing bacteria begin to decompose the waste and generate methane. Figure 1-1 illustrates the changes in typical LFG composition over time.

> More information about national GHG emissions from landfills and other sources is available from EPA's National Greenhouse Gas Emissions Data website. Additionally, facility-specific emissions data can be viewed using the EPA's Facility Level Information on GreenHouse gases Tool (FLIGHT).

1 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012*. U.S. Environmental Protection Agency. EPA 430-R-14-003. April 2014. http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

Figure 1-1. Changes in Typical LFG Composition after Waste Placement[2]

Bacteria decompose landfill waste in four phases. Gas composition changes with each phase and waste in a landfill may be undergoing several phases of decomposition at once. The time after placement scale (total time and phase duration) varies with landfill conditions.



Phase I: Aerobic bacteria—bacteria that live only in the presence of oxygen—consume oxygen while breaking down the long molecular chains of complex carbohydrates, proteins, and lipids that comprise organic waste. The primary byproduct of this process is carbon dioxide. Phase I continues until available oxygen is depleted.

Phase II: Using an anaerobic process—does not require oxygen—bacteria convert compounds created by aerobic bacteria into acetic, lactic and formic acids and alcohols such as methanol and ethanol. As the acids mix with the moisture present in the landfill and nitrogen is consumed, carbon dioxide and hydrogen are produced.

Phase III: Anaerobic bacteria consume the organic acids produced in Phase II and form acetate, an organic acid. This process causes the landfill to become a more neutral environment in which methane-producing bacteria are established by consuming the carbon dioxide and acetate.

Phase IV: The composition and production rates of LFG remain relatively constant. LFG usually contains approximately 50-55% methane by volume, 45-50% carbon dioxide, and 2-5% other gases, such as sulfides. LFG is produced at a stable rate in Phase IV, typically for about 20 years.

Approximately 251 million tons of MSW were generated in the United States in 2012, with less than 54 percent of that deposited in landfills.[3] 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 it has been landfilled. With a heating value of about 500 British thermal units (Btu) per standard cubic foot, LFG is a good source of useful energy, normally through the operation of engines or turbines. Many landfills collect and use LFG voluntarily to take advantage of this renewable energy resource while also reducing GHG emissions.

For more information on LFG modeling to estimate methane generation and recovery potential, see Chapter 2.

[2] Figure adapted from ATSDR 2008. Chapter 2: Landfill Gas Basics. In *Landfill Gas Primer - An Overview for Environmental Health Professionals.* Figure 2-1, pp. 5-6. http://www.atsdr.cdc.gov/HAC/landfill/PDFs/Landfill_2001_ch2mod.pdf

[3] Of the MSW generated in 2012, more than 34 percent was recovered through recycling or composting while about 12 percent was combusted with energy recovery. Source: U.S. EPA. 2012. *Municipal Solid Waste Generation, Recycling, and Disposal in the United States — Facts and Figures for 2012.* EPA-530-F-14-001. Figure 4, p. 3. http://www.epa.gov/osw/nonhaz/municipal/pubs/2012_msw_fs.pdf.

1.2 LFG Collection and Flaring

LFG collection typically begins after a portion of the landfill (known as a "cell") is closed to additional waste placement. Collection systems can be configured as either vertical wells or horizontal trenches. 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. 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. Horizontal trench systems are useful in deeper landfills and in areas of active filling. Some collection systems involve a combination of vertical wells and horizontal collectors. 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 1-2 illustrates the design of a typical vertical LFG extraction well, and Figure 1-3 shows a typical horizontal extraction well.

Figure 1-2. Vertical Extraction Well

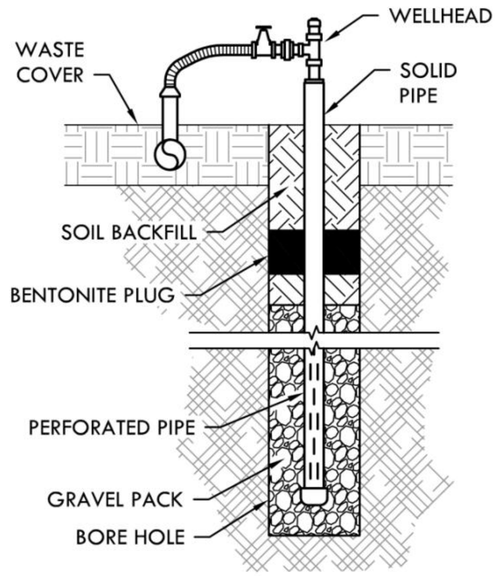
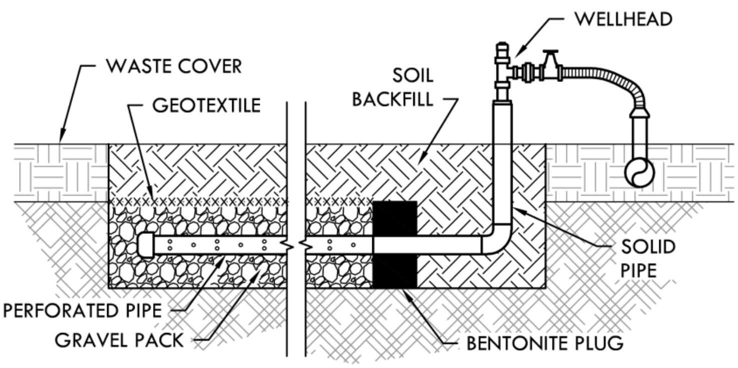


Figure 1-3. Horizontal Extraction Well



Condensate Collection. Condensate forms when warm gas from the landfill cools as it travels through the collection system. If condensate (water) is not removed, it can block the collection system and disrupt the energy recovery process. Techniques for condensate collection and treatment are described in Chapter 3.

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 startup and downtime of the energy recovery system 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 generation 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 (for example, before the addition of another engine) to prevent methane from being released into the atmosphere.

As shown in Figure 1-4, 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 (higher methane destruction rates) than open flares. They can also reduce noise and light nuisances.

Figure 1-4. Open (left) and Enclosed (right) Flares

A Closer Look at 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 required for a 40-acre collection system designed for 600 cubic feet per minute (cfm) of LFG (including a flare) is approximately $1,022,000, or $25,500 per acre (2013 dollars), assuming one well is installed per acre. Typical annual operation and maintenance (O&M) costs for collection systems are estimated to be $180,000, or $4,500 per acre.[4] If an LFG energy project generates electricity, often a landfill will use a portion of the electricity generated to operate the system and sell the rest to the grid to offset these operational costs. Flaring costs have been incorporated into these estimated capital and operating costs of LFG collection systems, because excess gas may need to be flared at any time, even if an energy generation system is installed.

For more information about the types of LFG collection systems, see Chapter 3.

1.3 LFG Treatment

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 depend on site-specific LFG characteristics and the type of energy recovery system employed. Boilers and most internal combustion engines generally require minimal treatment (usually dehumidification, particulate filtration and compression). Some internal combustion engines and many gas turbine and microturbine applications also require siloxane and hydrogen sulfide removal using adsorption beds, biological scrubbers and other available technologies after the dehumidification step.[5]

Figure 1-5 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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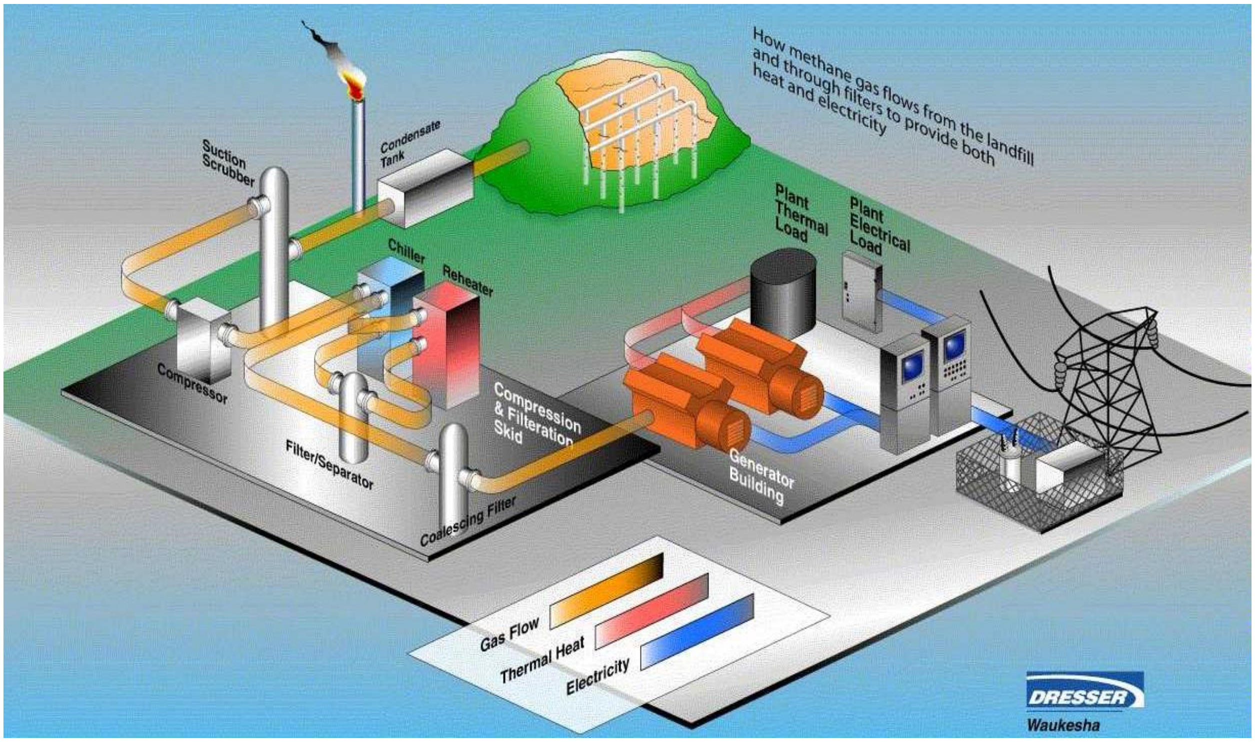
4 U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

5 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 components of the gas turbine, reducing the performance of the equipment and resulting in significantly higher maintenance costs. See Chapter 3 for further information.

Figure 1-5. LFG Collection, Treatment and Energy Recovery



Graphic courtesy of Dresser Waukesha

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 contaminants such as siloxane and sulfur that are present at elevated levels in some LFG.

For more information about the types of LFG treatment systems, see Chapter 3.

1.4 Uses of LFG

LFG energy projects first came on the scene in the mid- to late-1970s and increased notably during the 1990s as a track record for efficiency, dependability and cost savings was demonstrated. The enactment of federal tax credits and regulatory requirements for LFG collection and control for larger landfills also helped to spur the growth of LFG energy projects, as did other factors such as increased concerns about how methane emissions contribute to global climate change and market demands for renewable energy options.

Every million tons of MSW in a landfill is estimated to be able to produce approximately 432,000 cubic feet per day of LFG.

Through various technologies, the LFG could generate approximately 0.78 megawatts of power, or provide 9 million Btu per hour of thermal energy.

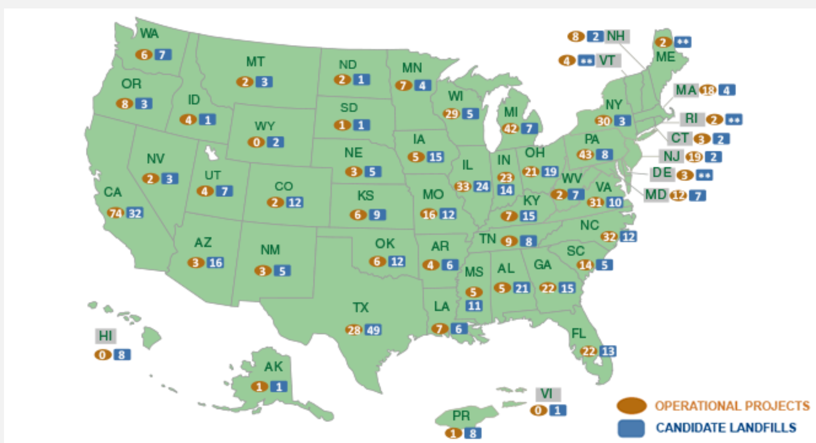
LMOP’s Landfill and LFG Energy Project database, which tracks the development of U.S. LFG energy projects and landfills with project development potential, indicates that 636 LFG energy projects are currently operating in 48 states and 1 U.S. territory. Roughly three-quarters of these projects generate electricity, while one-quarter are direct-use projects where 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. As illustrated in Figure 1-6, the 636 projects are estimated to generate 16 billion kilowatt (kW) hours (kWh) of electricity and supply 100 billion cubic feet of LFG to direct end users and natural gas pipelines annually.[6] 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 website.

Figure 1-6. Estimated LFG Energy Project Output in the United States (July 2014)

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 and Project Award Winners.

LMOP provides national and state-specific lists of operational projects and candidate landfills at www.epa.gov/lmop/projects-candidates.

Each list includes data on waste-in-place, LFG flow rates and other basic information about the landfill or project.



Electricity Generation

The three most commonly used technologies for LFG energy projects that generate electricity — internal combustion engines, gas turbines and microturbines — can accommodate a wide range of project sizes. Most (more than 70 percent) of the LFG energy projects that generate electricity use internal combustion engines, which are well-suited for 800 kW to 3 megawatts (MW) projects. Multiple internal combustion engine units can be used together for projects larger than 3 MW. Gas turbines are more likely to be used for large projects, usually 5 MW or larger. Microturbines, as their name suggests, are much smaller than gas turbines, with a single unit having between 30 and 250 kW in capacity, and are generally used for projects smaller than 1 MW. Small internal combustion engines are also available for projects in this size range.

[6] U.S. EPA. LMOP Landfill and LFG Energy Project database. July 2014.

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 engines, gas turbines or microturbine technologies.

Less common LFG electricity generation technologies include boiler/steam turbines and combined cycle applications. In boiler/steam turbine applications, LFG is combusted in a large boiler to generate steam that powers a turbine to create electricity. Combined cycle applications combine a gas turbine with a steam turbine, so that the gas turbine combusts the LFG and the steam turbine uses the 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.

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 electricity generation technologies, see Chapter 3.

Direct Use

Direct use of LFG can offer a cost-effective alternative for fueling combustion or heating equipment at facilities located within approximately 5 miles of a landfill. In some situations, longer pipelines may be economically feasible based on the amount of LFG collected, the fuel demand of the end user and the price of the fuel the LFG will replace. 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 with natural gas.

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 (cement, pottery or 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 (carbon dioxide and impurities removal) 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 (such as biodiesel or ethanol). In some cases, LFG is directly used as feedstock for an alternative fuel (for example, 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 direct-use technologies and others, see Chapter 3.

1.5 Environmental and Economic Benefits of LFG Energy Recovery

Developing LFG energy projects is an effective way to reduce GHG emissions, improve local air quality and control odors. This section highlights the numerous environmental and economic benefits that LFG energy projects provide to the community, the landfill and the energy end user.

Environmental Benefits

MSW landfills are the third-largest human-caused source of methane emissions in the United States.[7] Methane is a potent heat-trapping gas (more than 20 times stronger than carbon dioxide) and has a short atmospheric life (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 lessen the human impact on global climate change. In addition, all landfills generate methane, so there are many opportunities to reduce methane emissions by flaring or collecting LFG for energy generation.

Direct GHG 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 methane captured is converted to water and carbon dioxide when the gas is burned to produce electricity or heat.[8]

Indirect GHG 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 displacement avoids GHG emissions from fossil fuel combustion by an end user facility or power plant.[9]

GHG Equivalents[10]

The 636[11] LFG energy projects operational in 2014 reduce approximately 127 million metric tons of carbon dioxide equivalents (MMTCO_2e)/year of GHG emissions, which is equivalent to any one of the following:

Carbon sequestered annually by nearly 104 million acres of U.S. forests	*or*	**Carbon dioxide emissions from about 300 million barrels of oil consumed**	*or*	**Carbon dioxide emissions from more than 14.2 billion gallons of gasoline consumed**

7 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012*. U.S. Environmental Protection Agency. EPA 430-R-14-003. April 2014. http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

8 Carbon dioxide emissions from MSW landfills are not considered to contribute to global climate change because the carbon was contained in recently living biomass (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 logic is consistent with international GHG protocols such as the 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories, Volume 5: Waste. http://www.ipcc-nggip.iges.or.jp/public/2006gl/.

9 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.

10 U.S. EPA. Greenhouse Gas Equivalencies Calculator. http://www.epa.gov/cleanenergy/energy-resources/calculator.html.

11 U.S. EPA. LMOP Landfill and LFG Energy Project database. July 2014.

Direct and Indirect Reduction of Other Air Pollutants. The capture and use of LFG at a landfill improves local air quality in many ways. For example:

- Non-methane organic compounds that are present at low concentrations in LFG are destroyed or converted during combustion, which reduces possible health risks.
- For electricity projects, the avoidance of fossil fuel combustion at utility power plants means that fewer pollutants are released into the air, including 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.
- LFG energy use helps to avoid the use of limited, non-renewable resources such as coal and oil.
- Although the equipment that burns LFG to generate electricity generates some emissions, including nitrogen oxides, the overall environmental benefits achieved from LFG energy projects are significant because of the direct methane reductions, the indirect carbon dioxide reductions, and the direct and indirect reduction in other air pollutant emissions.

Other Environmental Benefits. Collecting and combusting LFG improves the quality of the surrounding community by reducing landfill odors that are usually caused by sulfates in the gas. Collecting LFG also improves safety by reducing gas migration to structures, where trapped or accumulated gas can create explosion hazards.

> The LFG Energy Benefits Calculator can be used to estimate direct methane reductions, indirect carbon dioxide reductions, and equivalent environmental benefits for an 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. 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 GHG emissions trading. 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, using the LFG as an energy resource can help pay down the capital cost required for the control system installation.

Examples

Electricity Generation and Combined Heat and Power at Catawba County Blackburn Landfill, North Carolina. 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 for the county over the project's lifetime. The LFG electricity provides Duke Energy (the electricity purchaser) with a renewable energy resource, and the GHG emission reductions are equivalent to the carbon dioxide emissions from about 343,000 barrels of oil consumed.

Combined Heat and Power at La Crosse County Landfill, Wisconsin. This project, recognized as an LMOP 2012 award winner, involves a public/private partnership between La Crosse County and Gundersen Health Systems. LFG from the county landfill is transported underground via a 2-mile pipeline constructed underneath Interstate 90 to generate green power for the local grid and to heat buildings and water at Gundersen's Onalaska campus. The sale of LFG provides La Crosse County with new revenue, and Gundersen's Onalaska Campus is 100 percent energy independent. Additionally, the landfill is the first in the state to achieve "Green Tier" status from the Wisconsin Department of Natural Resources.

For the End User. Businesses and other organizations, such as universities and government facilities, may save significantly on energy costs by choosing LFG as a direct fuel source. In addition, some companies report achieving indirect economic benefits through media exposure that portrays them as leaders in the use of renewable energy.

Examples

Direct Use of LFG at General Motors Plant in Indiana. 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.

Direct Use of LFG to Reduce Fuel Costs in Springfield, Ohio. 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 permitting and developing a direct-use project in Springfield, Ohio. Five years later, International began using LFG in place of natural gas in paint ovens, boilers and other equipment, saving $100,000 per year in fuel costs.

Using LFG to Save Energy Costs at BMW Manufacturing in South Carolina. BMW uses gas from Waste Management's Palmetto Landfill to fuel two gas turbine cogeneration units at BMW Manufacturing Landfill Gas Energy Projects in Greer, South Carolina. The project saves BMW approximately $5 million annually in energy costs.

Direct-Use of LFG at Decatur-Morgan County Landfill in Alabama. Winner of the LMOP 2011 Community Partner of the Year, Morgan County Regional Landfill took advantage of premium green power pricing through the Tennessee Valley Authority's Generation Partners program. Project developer Granger brought one Caterpillar 3516 engine on line in 2010, and the city brought a second engine on line in 2011 for a combined capacity of 1.6 MW. Waste heat from the second engine provides heating to the city's recycling center during the winter.

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 generation 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, lodging 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 is spent within the local economy on goods and services, resulting in indirect economic benefits. In some cases, LFG energy projects have led new businesses (such as brick and ceramics plants, greenhouses or craft studios) to locate near the landfill to use LFG. These new businesses add depth to the local economy.

Examples

Stimulating Local Economies. Construction of a direct-use project using LFG from the Lanchester Landfill in Narvon, Pennsylvania, created more than 100 temporary construction jobs 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 local hotel stays).

Raising Awareness and Saving Money. 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.

Investing in Schools. The ecology club at Pattonville High School in Maryland Heights, Missouri, suggested that the school board 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.

Revenue Creation[12]			
Economic Benefits	Typical 3 MW LFG electricity project	Typical Direct Use Project (1,040 scfm)	
		5-mile pipeline	10-mile pipeline
New project expenditures for the purchase of generators, and gas compression, treatment skid and auxiliary equipment	$1.5 million	$1.1 million	$2.2 million
Increase in state-wide economic output	$4.1 million	$2.8 million	$5.2 million

MW: megawatt   scfm: standard cubic feet per minute

For more information about these project economics and financing, see Chapter 4.
For more information about options when setting up a contract, see Chapter 5.
LMOP provides information about funding resources in the online funding guide.

1.6 Overview of the Regulatory Framework

Landfills and LFG energy projects can be subject to air quality, solid waste, and water quality regulations and permitting requirements. State and local governments typically develop their own regulations for carrying out the federal mandates; therefore, specific requirements differ among states. In addition, project developers should contact relevant federal agencies and state agencies for more detailed, current information and to obtain applications for various types of construction and operating permits. An overview of the federal regulatory framework is presented below. It is important for project developers to review applicable requirements and regulations. Project developers are responsible for ensuring compliance with applicable regulations.

Further information for states is available on LMOP's State Resources page.
MSW landfills are required to report GHG emissions and other data if their annual CH_4 generation is greater than or equal to 25,000 metric tons of CO_2e. Learn more about reporting requirements at EPA's Greenhouse Gas Reporting Program website including specific requirements applicable to MSW landfills (Subpart HH).
See Chapter 5 for more information about federal regulations.

Clean Air Act (CAA)

The CAA regulates emissions of pollutants to protect the environment and public health. The CAA contains five provisions that may affect LFG energy projects: (1) New Source Performance Standards (NSPS) and Emission Guidelines (EG), (2) National Emission Standards for Hazardous Air Pollutants (NESHAP), (3) New Source Review (NSR) permitting, (4) Title V permitting, and (5) Information Collection Authority, which was used to implement the GHG reporting program.

NSPS for Internal Combustion Engines. EPA promulgated a final rule on spark ignition internal combustion engines on August 29, 2011. This final rule requires more stringent standards for stationary compression ignition engines and makes minor revisions to the standards of performance for new stationary spark ignition internal combustion engines in order to correct minor errors and to mirror certain revisions finalized to provide consistency where appropriate for the regulation of stationary internal combustion engines. Rule and implementation information for NSPS for internal combustion engines is available on EPA's Air Toxics Website.

12 U.S. EPA. LMOP Landfill and LFG Energy Project database. July 2014.

NSPS and EG for 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. 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. More information on NSPS and EG for MSW landfills can be found online at EPA's Air Toxics Website.

NESHAP for MSW Landfills. 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 affect the same landfills and have the same control requirements as the NSPS/EG. The control requirements are the same as the NSPS/EG with one exception — large landfills (those that exceed the 2.5 million megagram [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 megagrams (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. A Proposed Rule introduced in July 17, 2014 for 40 CFR part 60, subpart XXX, modifies the 50 Mg/year threshold to 40 Mg/yr.

Reporting of GHG. Landfills and owners of stationary combustion equipment that burns LFG may be required to report GHG emissions under 40 Code of Federal Regulations (CFR) Part 98. Part 98 requires reporting only; it does not contain any emission limits or require any emission reductions. MSW landfills are required to report if their annual methane generation is equivalent to or greater than 25,000 metric tons of carbon dioxide equivalent. For landfills, applicability is based on methane generation (calculated using equations in Part 98) rather than actual emissions. To assist in the determination of applicability, EPA has developed an online applicability screening tool that includes a landfill calculation utility. LFG energy projects that are not part of a landfill facility are also required to report GHG emissions from their combustion equipment if they meet the applicability thresholds in Part 98 for listed industrial source categories or for general stationary fuel combustion.

NESHAP for Internal Combustion Engines. On March 9, 2011, EPA promulgated amendments to NESHAP (40 CFR Part 63, Subpart ZZZZ) for existing internal combustion engines not already covered by earlier EPA regulations. Originally published in August 2010, the rule added emission standards, monitoring, recordkeeping, and reporting requirements for LFG-fired internal combustion engines at major and area sources of hazardous air pollutants. Two main requirements are:

- Existing, non-emergency, spark ignition, LFG-fired engines located at major sources with a site rating greater than or equal to 100 horsepower and less than or equal to 500 horsepower are limited to emissions of carbon monoxide of 177 parts per million by volume on a dry basis at 15 percent oxygen.
- Existing, non-emergency, spark ignition, LFG-fired engines of any size located at area sources have management practice standards instead of a carbon monoxide limit.

The final rule and earlier rules are available on EPA's Air Toxics Website.

NESHAP for Major Source Boilers and Process Heaters. On March 21, 2011, EPA promulgated NESHAP for existing and new boilers and indirect-fired process heaters at major sources of hazardous air pollutants. EPA subsequently published a notice of intent to reconsider specific provisions of the rule. EPA took final action on January 31, 2013. A unit used as a control device to comply with another maximum achievable control technology (MACT) standard is exempt from the rule if greater than 50 percent of its average annual heat input over a 3-year period is from the gas stream regulated under that standard. Otherwise, LFG-fired units will be subject to tune-up work practices if they operate infrequently or at very low loads (as specified in the rule), or have a design heat input capacity less than 10 million British thermal units (MMBtu) per hour, or fire a gas stream that either meets a minimum methane content or heating value or does not exceed the maximum mercury concentration. Units not meeting the above criteria would be subject to emission limits for particulate matter (or non-mercury metals), hydrochloric acid, mercury and carbon monoxide. The final rule is available on EPA's Air Toxics Website.

Overview of NSR Permitting. New LFG energy projects may be required to obtain construction permits under the NSR. Depending on the area where 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 (attainment or nonattainment area). The location and size of the LFG energy project will dictate what kind of construction and operating permits are required.

Resource Conservation and Recovery Act (RCRA) Subtitle D

All RCRA Subtitle D requirements (requirements for nonhazardous solid waste management) must be satisfied before an LFG energy project can be developed. 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. 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. If methane emissions exceed permitted limits, corrective action (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

NPDES permits regulate discharges of pollutants to surface waters. 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 because of changes in temperature and pressure 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. The permits, which typically last 5 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 offices can provide further information on these permits.

Clean Water Act (CWA) Section 401

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 these 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 where the discharge will originate.

Other Federal Permit Programs and Regulatory Requirements

Other federal permits could apply to LFG energy project development, as follows:

- 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.
- Projects that transport LFG via pipeline are subject to 49 CFR Part 192 — *Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards* if the LFG pipeline crosses or impedes public property. The Department of Transportation's Office of Pipeline Safety (OPS) is the main regulatory agency responsible for regulating the operation and maintenance (O&M) of jurisdictional natural gas pipelines. Many state agencies have adopted the regulations and can regulate jurisdictional pipelines within their states.
- The Historic Preservation Act of 1966 or the Endangered Species Act could apply if power lines or gas pipelines associated with a project infringe on 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.

1.7 Steps to Developing LFG Energy Projects

The following section provides a basic overview of nine general steps involved in developing an LFG energy project. More specific details about each of these steps are provided in the remaining chapters of this handbook, as noted below.

Step 1 Estimate LFG Recovery Potential and Perform Initial Assessment

The first step is to determine whether the landfill is likely to produce enough methane to support an energy recovery project. Initial screening criteria include:

- Does the landfill contain at least 1 million tons of MSW?
- Does the landfill have a depth of 50 feet or more?
- Is the landfill open or recently closed?
- Does the site receive at least 25 inches of precipitation annually?
- Does the landfill contain enough organic content to generate sufficient LFG?

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; many successful LFG energy projects have been developed at smaller, older and more arid landfills. If it is determined that the energy recovery option is viable, then it is important to estimate the amount of recoverable gas that will be available over time. EPA's LandGEM can provide a more detailed analysis of the potential for generation of LFG.

An important factor for LFG generation is the organic content of the MSW. Waste composed of high organic content will produce more LFG than waste with lower organic content. Construction and Demolition (C&D) landfills, for example, are not expected to generate large quantities of LFG and are often not viable for an energy generation system.

Details about modeling and estimating LFG flow are presented in Chapter 2.

Step 2 Evaluate Project Economics

The next step 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. 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 can help with preliminary economic evaluation.

Details about project technology options are presented in Chapter 3.
Chapter 4 outlines the process for assessing project economics and financing options.

Step 3 Establish Project Structure

Implementation of a successful LFG energy project begins with identifying the appropriate management structure. For example, options for managing an LFG energy project include:

- The landfill owner develops and manages the project internally.
- The landfill owner teams with an external project developer so that the developer finances, constructs, owns and operates the project.
- The landfill owner teams with partners (such as an equipment supplier or energy end user).

LMOP can assist with project partnering by identifying potential matches and distributing RFPs. The LMOP Locator tool available for download online allows users to search for facilities that could potentially benefit from LFG or search for landfills that could potentially provide LFG to an interested party.

An overview of the types of contracts used for LFG energy projects is provided in Chapter 5.
See Chapter 6 for more information on project structures and evaluating project partners.

Step 4 Draft Development Contract

The terms of LFG energy project partnerships should be formalized in a development contract. The contract identifies which partner owns the gas rights and the rights to potential emissions reductions. The contract also establishes each partner's responsibilities, including design, installation and 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 objectives and limitations of the participants.

See Chapter 5 to learn about LFG contracts and permitting requirements.
Chapter 6 for details about selecting project partners.

Step 5 Negotiate Energy Sales Contract (Off-Take Agreement)

The LFG energy project owner and the end user negotiate an energy sales contract that specifies the amount of gas or power to be delivered by the project owner to the end user and the price to be paid by the end user for the gas or power. The terms of the energy sales contract typically dictate the success or failure of the LFG energy project because they secure the project's source of revenue. Therefore, successfully obtaining this contract is a crucial milestone in the project development process. Negotiating an energy sales contract involves the following actions: evaluating the end user's need for gas or power, preparing a draft offer contract, developing the project design and pricing, preparing and presenting a bid package, reviewing contract terms and conditions, and signing the contract. Because contract negotiation is often a complex process, owners and developers should consult an expert for further information and guidance.

See Chapter 5 and Chapter 6 for more information about contracts.

Step 6 Secure Permits and Approvals

Obtaining the required permits (environmental, siting and others) is an essential step in the development process. Permit conditions often affect project design, and neither construction nor operation may begin until the appropriate permits are in place. The process of permitting an LFG energy project can take anywhere from 6 to 18 months (or longer) to complete, depending on the 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. The landfill owner should contact and meet with regulatory authorities to identify requirements and educate the local officials, landfill neighbors, and nonprofit and other public interest and community groups about the benefits of the project. LMOP's State Resources page lists websites for state organizations that can provide useful information regarding state-specific regulations and permits.

See Chapter 5 for more information about permits.

Step 7 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 sources are available, including equity investors, loans from investment companies or banks, and 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. In addition to financing options, there are a variety of financial incentives available at the federal and state levels. Details about specific federal, state and local financing programs and incentives are available through LMOP's Funding Guide webpage.

See Chapter 4 for more details about financing mechanisms.
Chapter 5 and Chapter 6 review additional considerations related to contracts and partnerships.

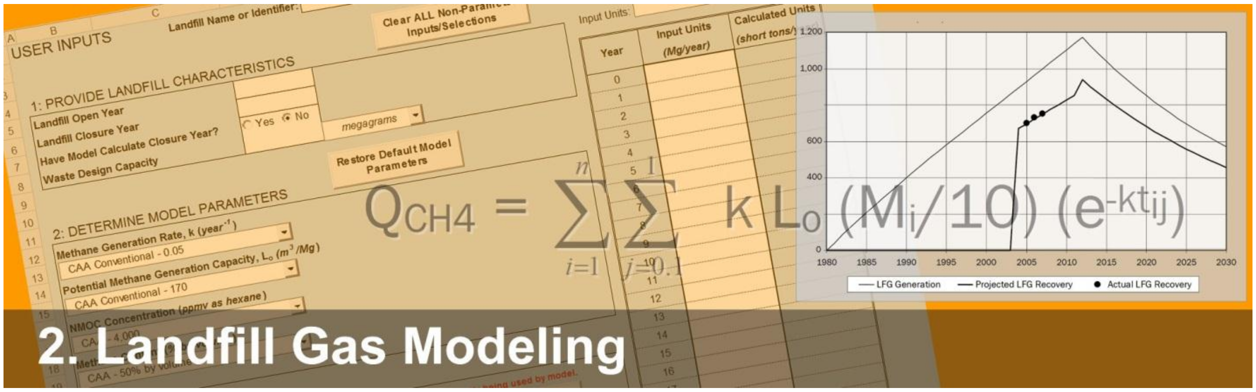
Step 8 Contract for Engineering, Procurement, and Construction (EPC) and O&M Services

The construction and operation of LFG energy projects is complex, so it may be in the interest of the landfill owner to hire a firm with proven experience gained over the course of implementing similar projects. Landfill owners who choose to contract with EPC and O&M firms should solicit bids from several EPC or O&M contractors before a contract is negotiated. In most cases, the selected EPC or O&M contractor conducts the engineering design, site preparation and plant construction, and startup testing for the LFG energy project.

Chapter 6 provides more information about coordinating with project partners.

Step 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.



2. Landfill Gas Modeling

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. It is an important step in the project development process because it provides an estimate of the amount of recoverable LFG that will be generated over time. LFG modeling is performed for regulatory and non-regulatory purposes. Regulatory applications of LFG models are conducted for landfills in the United States to establish the requirements for installation and operation of the gas collection and control system. Non-regulatory applications of LFG models typically include any of the following:

- Evaluating the feasibility of the LFG energy project
- 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. The 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 NSPS require modeling to evaluate the applicability of and compliance with the rule. For regulatory applications, the modeler must use the specific procedures, default values and test methods prescribed in the rule.

Refer to the appropriate regulations (such as the NSPS [40 CFR Part 60 Subpart WWW] and related documentation) for details.

2.1 Introduction to LandGEM

The EPA's LandGEM is a Microsoft Excel-based software application that uses a first-order decay rate equation to calculate estimates for methane and LFG generation. LandGEM is the most widely used LFG model and is the industry standard for regulatory and non-regulatory applications in the United States.

The first-order decay rate equation produces an estimate for the amount of methane that will be generated at a specific time.

The latest version of LandGEM (v. 3.02) was released in May 2005 and can be downloaded from the EPA's website at www.epa.gov/ttn/catc/products.html#software.

The First-Order Decay Equation

LandGEM uses the first-order decay equation below to estimate methane generation. LFG generation estimates are based on the methane content of the LFG. The default methane content of LFG is 50 percent, which is both the industry standard value and LMOP's recommended default value.

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

Where:

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

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

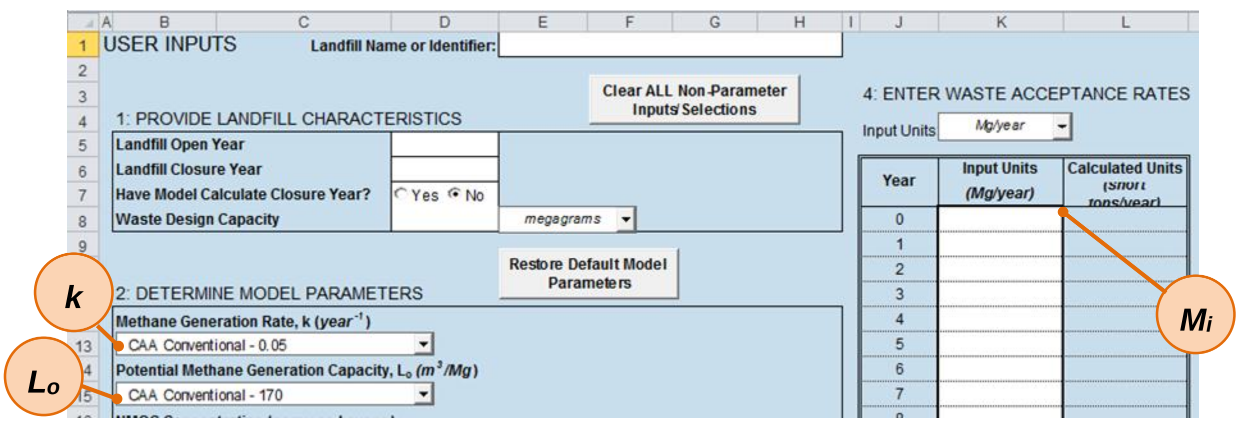
t_{ij} = age of the j^{th} section of waste mass disposed in the i^{th} year (decimal years)

LandGEM assumes that methane generation is at its peak shortly after initial waste placement (after a short time lag when anaerobic conditions are established in the landfill). The model also assumes that the rate of landfill methane generation then decreases exponentially (first-order decay) as organic material is consumed by bacteria.

Model Inputs

Only three of the variables in the first-order decay equation require user inputs (M_i, L_0 and k). Inputs are entered on the "USER INPUTS" worksheet in LandGEM (see Figure 2-1).

Figure 2-1. LandGEM User Inputs Worksheet



***k* (*Methane Generation Rate Constant*):** 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 1/year or yr^{-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.

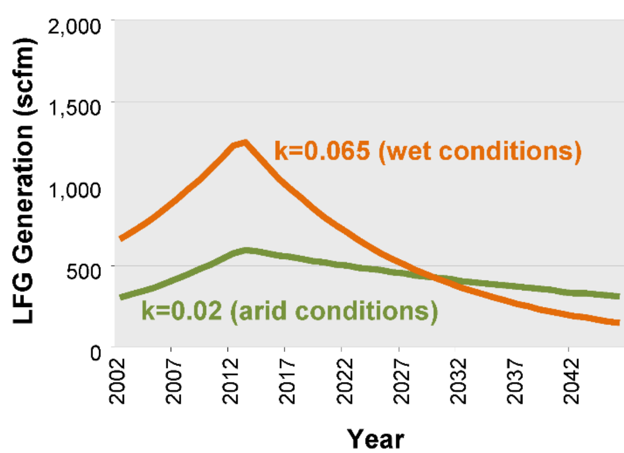
Moisture conditions within a landfill strongly influence k values and waste decay rates. Waste decay rates and k values are very low at desert sites, tend to be higher at sites in wetter climates, and reach maximum levels under moisture-enhanced conditions. Annual precipitation is often used as a surrogate for waste moisture because of 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 range from approximately 30 to 60°C (85 to 140°F) except at shallow, unmanaged landfills in very cold climates (as in landfills located in areas above 50 degrees latitude). For these landfills, waste decay rates and k values tend to be lower.

***L_0* (Potential Methane Generation Capacity):** 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. EPA determined that the appropriate values for L_0 range from 56.6 to 198.2 m^3 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 organic content of the waste determines the L_0 value, and not the wet weight measured and recorded at landfill scalehouses, as water does not generate LFG. LandGEM sets L_0 to a default value of 170 m^3/Mg to represent a conventional landfill.[2]

***M_i* (Annual Waste Disposal Rates):** Estimated waste disposal rates are the primary determinant of LFG generation in any first-order decay-based model. 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.

Figure 2-2 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 2-2. LFG Generation Variance by k Value



Model Outputs

After the model inputs are entered, emission estimates can be viewed in tabular format on the "RESULTS" worksheet. The results include annual data for waste inputs, waste-in-place amounts, and estimates of total LFG generation, methane, carbon dioxide and non-methane organic compounds (NMOCs). The results also may be viewed graphically on the "GRAPHS" worksheet, which plots emission estimates by year. LFG and methane generation estimates are the output parameters used for non-regulatory LFG predictions.

For additional details about the LandGEM model, see the LandGEM User's Manual.

1 U.S. EPA. 1995. *Air Emissions from Municipal Solid Waste Landfills — Background Information for Final Standards and Guidelines*. EPA-453/R-94-021. p. 2-60.

2 U.S. EPA. 2005. Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide. EPA-60/R-05/047. p. 17.

2.2 Estimating LFG Collection

Developing accurate estimates for the amount of available LFG is critical to evaluating the technical and economic feasibility of an LFG project.

Once the LFG and methane generation amounts are estimated, the next step is to estimate the amount of LFG that can be collected.

Estimating Collection Efficiency

Collection efficiency is a measure of the ability of a gas collection system to capture LFG generated at the landfill. The LFG generation estimate produced by the model is multiplied by the collection efficiency to estimate the volume of LFG that can be recovered for flaring or use in an LFG energy project. Considerable uncertainty exists regarding collection efficiencies achieved at landfills because the total LFG generated is always estimated.

To help address this uncertainty, EPA has published estimates of reasonable collection efficiencies for landfills in the United States that meet U.S. design standards[3] and have "comprehensive" LFG collection systems. A "comprehensive" LFG collection system is made up of vertical wells and or horizontal collectors that cover 100 percent of all waste areas within 1 year after the waste is deposited. Reported collection efficiencies at such landfills typically range from 50 to 95 percent, with an average of 75 percent most commonly assumed.[4] Since most landfills, particularly those that are still receiving wastes, have less than 100 percent collection system coverage, 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 covered with wells. This adjustment also can be applied to account for areas where wells are not fully functioning.

The modeler typically assumes that a comprehensive system will be installed for sites without collection systems, and that future collection efficiency estimates may reflect planned collection system enhancements. Collection efficiency usually increases after site closure when disposal operations no longer interfere with LFG system operations and a final cover is installed.

Estimating LFG Recovery

The final step in the modeling process is to estimate annual LFG recovery, which is calculated as the product of LFG generation and collection efficiency. Table 2-1 shows a recommended format for estimating LFG recovery.

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/yr)	(%)	(scfm)	(m^3/yr)
Year 1							
Year 2							
Year X (final year)							

m^3/yr: cubic meters per year   scfm: standard cubic feet per minute

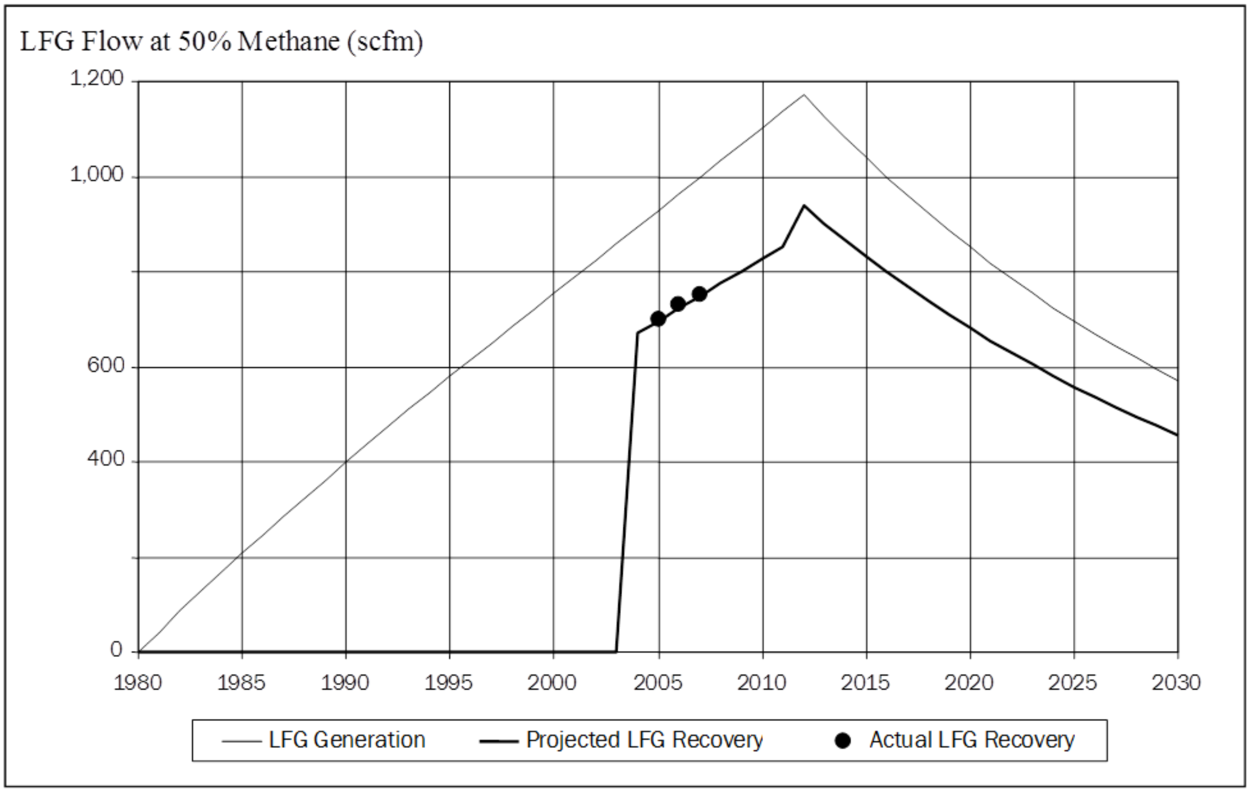
3 Landfills that meet or exceed the requirements in the 40 CFR Parts 257 and 258 RCRA Subtitle D Criteria.

4 U.S. EPA. 2008. Background Information Document for Updating AP42 Section 2.4 Municipal Solid Waste Landfills, EPA/600/R-08-116. http://www.epa.gov/ttn/chief/ap42/ch02/.

To illustrate LFG recovery projections over time, both LFG generation and recovery can be displayed in a line graph. The x-axis (horizontal) shows the year, and the y-axis (vertical) shows the LFG flow at 50 percent methane (in standard cubic feet per minute [scfm]). The graph can be used to assess the model's accuracy by displaying actual recovery as dots for sites with operating collection systems and recovery data. Figure 2-3 shows a sample model output graph for a landfill that opened in 1980, installed a gas collection system in 2003,[5] and accepted waste through 2011. Measurements of recovered LFG are shown as dots.

LMOP recommends seeking the help of an experienced professional LFG modeler to perform model calibration, which involves adjusting model k and L_0 values so that the projected LFG recovery rates closely match actual recovery.

Figure 2-3. LFG Generation and Recovery Rates



Special Considerations for Bioreactor and Leachate Recirculation Landfills

Some landfills deliberately introduce liquids into the waste in a controlled manner to speed up the waste decay process and shorten the time period for 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 content less than 40 percent are considered "leachate recirculation" landfills.

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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.

The introduction of liquids into the landfill causes significant increases in waste decay rates and k values. LFG generation increases more rapidly while the landfill is receiving waste and decreases more rapidly once disposal stops, but the total LFG generation over the long term remains the same. L_0 values should not be affected by liquids introduction because only the rate of LFG generation is affected.

- k value for bioreactor landfills: LandGEM provides a default k value of 0.7 for modeling bioreactor landfills (the "inventory wet" value). LMOP, however, recommends assigning a k value of 0.3 for bioreactors based on a study conducted by the University of Florida.[7]
- k value for leachate recirculation landfills: 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.

In some instances, 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.

Visit the EPA's website to learn more about bioreactors.

2.3 Model Limitations

Accurate estimates for LFG recovery are critical to the proper design and financial success of LFG energy projects. LFG modelers should be aware of factors that can produce error within a model and use appropriate inputs to avoid significantly overestimating the amount of recoverable LFG. Factors that can affect the accuracy of LFG recovery projections include:

- ***Inaccurate assumptions.*** Inaccurate assumptions about variables such as organic content, future disposal rates, site closure dates, wellfield buildout, expansion schedules or collection efficiencies can result in large errors in predicting future recovery.
- ***Limited or poor quality disposal data.*** Significant model error can be introduced if good disposal data are not available.
- ***Poor-quality flow data 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 are representative of long-term average recovery.
- ***Atypical waste composition.*** Waste composition data are often not available to determine if unusual waste composition is a cause of model inaccuracy. However, the risk can be minimized by introducing sample collection procedures to better determine waste composition.
- ***Limitations because of 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

[7] U.S. EPA. 2005. *First-Order Kinetic Gas Generation Model Parameters for Wet Landfills*. EPA-600/R-05/072. http://nepis.epa.gov/Adobe/PDF/P100ADRJ.pdf.

3. Project Technology Options

The goal of a LFG energy project is to convert LFG into a useful form of energy. Hundreds of LFG energy projects currently operate in the United States, involving public and private organizations, small and large landfills, and various types of technologies. The most common LFG energy applications include:

- Electricity (power production and cogeneration) – LFG extracted from the landfill is converted to electricity
- Direct use of medium-Btu gas – treated LFG is used as a direct source of fuel
- Upgrade to vehicle fuel or pipeline-quality (high-Btu) gas – LFG is converted to produce the equivalent of natural gas, CNG or LNG

For example, LFG is used to produce electricity and heat in cogeneration applications. Direct use applications include heating greenhouses, firing brick kilns, fueling garbage trucks and providing fuel to chemical and automobile manufacturing businesses. Table 3-1 shows a breakdown of technologies used in operational LFG projects in 2014.

The remainder of this chapter provides a brief overview of design factors and technology options for LFG energy projects, followed by a discussion of considerations in technology selection.

Table 3-1. Operational Project Technologies

Project Technology	Projects[1]
Electricity Projects	
Internal combustion engine (reciprocating engine)	352
Cogeneration	47
Gas turbine	32
Microturbine	12
Steam turbine	11
Combined cycle	9
Stirling cycle engine	2
Direct-Use Projects	
Boiler	61
Direct thermal	48
High-Btu	34
Leachate evaporation	15
Alternative fuel (CNG or LNG)	6
Greenhouse	6
Medium-Btu gas injected into natural gas pipeline	1

For more information about LFG collection, flaring and treatment system components, see Chapter 1.

1 U.S. EPA LMOP. Landfill and LFG Energy Project Database. July 2014.

3.1 Design Factors

Selecting the best technology options for a project involves consideration of several key design factors, beginning with estimating the LFG recovery potential for the landfill. In general, the volume of waste controls the potential amount of LFG that can be extracted from the landfill. Site conditions, LFG collection efficiency and the flow rate for the extracted LFG also significantly influence the types of technologies and end uses that are most feasible for a project. Design considerations for gas collection and treatment systems are presented below.

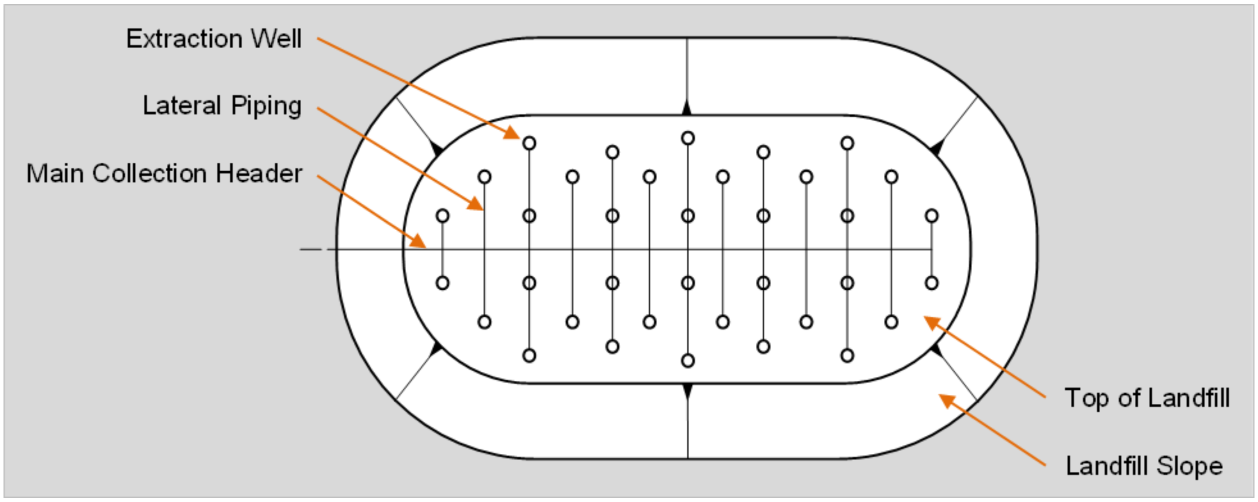
Gas Collection Systems

Collection systems can be configured as vertical wells, horizontal trenches or a combination of both. Advantages and disadvantages of each type of well are listed in Table 3-2. Regardless of whether wells or trenches are used, each wellhead is connected to lateral piping that transports the LFG to a main collection header, as illustrated in Figure 3-1. The collection system should be designed so that the operator can monitor and adjust the gas flow if necessary.

Table 3-2. Advantages and Disadvantages of Vertical and Horizontal LFG Collection Wells

Vertical Wells		Horizontal Wells	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
▪ Minimal disruption of landfill operations if placed in closed area of landfill ▪ Most common design ▪ Reliable and accessible for inspection and pumping	▪ Increased operation and maintenance required if installed in active area of landfill ▪ Availability of appropriate equipment ▪ Delayed gas collection if installed after site or cell closes	▪ Facilitates earlier collection of LFG ▪ Reduced need for specialized construction equipment ▪ Allows extraction of gas from beneath an active tipping area on a deeper site	▪ Increased likelihood of air intrusion until sufficiently covered with waste ▪ More prone to failure because of flooding or landfill settlement

Figure 3-1. Sample LFG Extraction Site Plan



LFG Treatment Systems

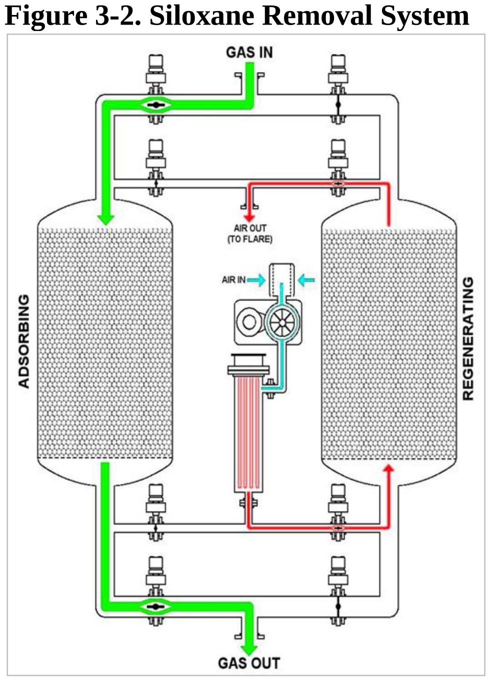
Before LFG can be used in a conversion process, it must be treated to remove condensate, particulates and other impurities. Treatment requirements depend on the end use.

- Treatment systems for LFG electricity projects typically include a series of filters to remove contaminants that can damage components of the engine and turbine and reduce system efficiency.
- Minimal treatment is required for direct use of LFG in boilers, furnaces or kilns.
- Advanced treatment is required to produce high-Btu gas for injection into natural gas pipelines or production of alternative fuels.

Treatment systems can be divided into primary 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 using equipment often referred to as “knockout” devices. It is common to use gas cooling and compression to remove water vapor or humidity from the LFG. Gas cooling and compression have been used for many years and are 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, including both physical and chemical treatments. The type of secondary treatment depends on the constituents that need to be removed for the end use. Two of the trace contaminants that may have to be removed from LFG are siloxanes and sulfur compounds.

- ***Siloxanes*** are found in household and commercial products that end up in solid waste and wastewater (a concern for landfills that take wastewater treatment sludge). 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) collects on the inside of internal combustion engines and gas turbines and on boiler tubes, potentially reducing performance and increasing maintenance costs. The need for treatment depends on the level of siloxane in the LFG and on manufacturer recommendations for the technology selected. Removal of siloxane can be both costly and challenging, so the decision to invest in siloxane treatment is project dependent.
- ***Sulfur compounds***, which include sulfides and disulfides (for example, hydrogen sulfide), are corrosive in the presence of moisture. These compounds will be at relatively low concentrations, and the LFG may not require any additional treatment at landfills accepting only typical MSW. The compounds tend to be at higher concentration in landfills that accept C&D materials, and additional treatment is more likely to be necessary.

Figure 3-2. Siloxane Removal System



The most common technologies used for secondary treatment are adsorption and absorption. Adsorption, which removes siloxanes from LFG, is a process by which contaminants adhere to the surface of an adsorbent such as activated carbon or silica gel. Figure 3-2 illustrates a common type of adsorption. Other gas treatment technologies that can remove siloxanes include subzero refrigeration and liquid scrubbing. Absorption (or scrubbing) removes compounds (such as sulfur) from LFG by introducing a solvent or solid reactant that produces a chemical/physical reaction. Advanced treatment technologies that remove carbon dioxide, 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 3.4.

3.2 Electricity Generation

Producing electricity from LFG continues to be the most common beneficial use application, accounting for about three-fourths 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.

Internal Combustion Engines

The internal combustion engine is the most commonly used conversion technology in LFG applications because of its relatively low cost, high efficiency and engine sizes that complement the gas output of many landfills (see Figure 3.3). Internal combustion engines have generally been used at landfills where gas quantity is capable of producing 800 kW to 3 MW, or where sustainable LFG flow rates to the engines are approximately 0.4 to 1.6 million cfd at 50 percent methane. Multiple engines can be combined together for projects larger than 3 MW. Table 3-3 provides examples of available sizes of internal combustion engines.

Figure 3-3. Internal Combustion Engines

Table 3-3. Internal Combustion Engine Sizes

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

cfm: cubic feet per minute kW: kilowatt MW: megawatt

Internal combustion engines are efficient at converting LFG into electricity, achieving electrical efficiencies in the range of 30 to 40 percent. Even greater efficiencies are achieved in 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.

Examples

The Lycoming County Landfill Dual Cogeneration and Electricity Project in Pennsylvania, an LMOP 2012 award winning project, used an innovative permitting approach and a creative power purchase agreement. LFG is combusted in four internal combustion engines (6.2 MW), which supplies 90 percent of the landfill complex's power and thermal needs and 80 percent of the electricity needs of the Federal Bureau of Prisons' Allenwood Correctional Complex. The county receives revenue for the project, and the bureau gains power price stability and can count the LFG use toward meeting federal renewable energy requirements.

For more information about CHP, see the CHP Partnership's Biomass Combined Heat and Power Catalog of Technologies and the Catalog of CHP Technologies.

Gas Turbines

Figure 3-4. Gas Turbine

Gas turbines, as shown in Figure 3-4, are typically used in larger LFG energy projects, where LFG flows exceed a minimum of 2 million cfd and are sufficient to generate a minimum of 3 MW. Gas turbine systems are widely used in larger LFG electricity generation projects because they have significant economies of scale. The cost per kW of generating capacity drops as the size of the gas turbine increases, and the electric generation efficiency generally improves as well. 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 capture additional electricity, can boost system efficiency to approximately 40 percent. As with simple-cycle gas turbines, combined-cycle configurations are also less efficient at partial load.

Advantages of gas turbines are that they are more resistant to corrosion damage than internal combustion engines and have lower nitrogen oxides emission rates. Additionally, gas turbines are relatively compact and have low O&M costs compared with internal combustion engines. However, LFG treatment to remove siloxanes may be required to meet manufacturer specifications.

A primary disadvantage of gas turbines is that they require high gas compression of 165 pound-force per square inch gauge (psig) or greater. As a result, more of the plant's power is required to run the compression system (creating causing a high parasitic load loss).

Examples

LFG is piped 4 miles from the Arlington Landfill in Arlington, Texas, to the Fort Worth (Village Creek) Wastewater Treatment Plant and is used to co-fire two 5.2 MW gas turbine generators.

Residents from three municipalities and Waste Management, Inc., formed Green Knight Economic Corporation, an independent non-profit organization that invested the revenue from the sale of the LFG generated by a 9.9 MW power plant with three gas turbines.

Microturbines

Figure 3-5. Microturbine

Microturbines have been sold commercially for landfill and other biogas applications since early 2001 (see Figure 3-5). Generally, costs for a microturbine project are higher than for internal combustion engine project costs based on a dollar-per-kW installed capacity.[2] However, several reasons for using microturbine technology instead of internal combustion engines include:

- Require less LFG volume than internal combustion engines
- Can use LFG with a lower percent methane (35 percent methane)
- Produce lower emissions of nitrogen oxides
- Can add and remove microturbines as gas quantity changes
- Interconnection is relatively easy because of the lower generation capacity

2 Wang, Benson, Wheless. 2003. *Microturbine Operating Experience at Landfills.* Solid Waste Association of North America (SWANA) 26th Annual Landfill Gas Symposium (2003), Tampa, Florida.

LFG was not treated sufficiently in early microturbine applications, which resulted in system failures. Typically, LFG treatment is required to remove moisture, siloxanes and other contaminants. This treatment is composed of the following components:

- Inlet moisture separator
- Rotary vane type compressor
- Chilled water heat exchanger (reducing LFG temperature to 40ºF)
- Coalescing filter
- LFG reheat exchanger (to add 20 to 40ºF above dew point)
- Further treatment of the moisture-free LFG in vessels charged with activated carbon or other media (optional)

Microturbines typically 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

Example

The Fort Benning Landfill in Fort Benning, Georgia operates a 0.25 MW capacity microturbine project that generates electricity. This project began in November 2011 and has direct current year emission reductions of 0.0113 $MMTCO_2e$/yr.

The All Purpose Landfill located in Santa Clara, California has been operating a 0.75 MW capacity microturbine project since December 2009. The project collects approximately 0.403 million standard cubic feet per day (mmscfd) of LFG and direct methane reductions from this energy project is approximately 0.0339 $MMTCO_2e$/yr.

Electricity Generation Summary

Table 3-4 presents examples of typical costs for several technologies, including costs for a basic gas treatment system typically used with each technology. The costs of energy generation using LFG can vary greatly and depend on many factors, including the type of electricity generation equipment, its size, the necessary compression and treatment system, and the interconnect equipment. Table 3-5 provides a summary of the advantages and disadvantages associated with each electricity generating technology.

Table 3-4. Examples of Typical Costs[3]

Technology	Typical Capital Costs ($/kW)*	Typical Annual O&M Costs ($/kW)*
Internal combustion engine (> 800 kW)	$1,800	$180
Small internal combustion engine (< 800 kW)	$2,400	$220
Gas turbine (> 3 MW)	$1,800	$180
Microturbine (< 1 MW)	$2,800	$230

* 2013 dollars kW: kilowatt MW: megawatt

3 U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

Table 3-5. Advantages, Disadvantages and Treatment Requirements Summary (Electricity)

Advantages	Disadvantages	Treatment
Internal combustion engine		
▪ High efficiency compared with 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 with gas turbines and microturbines ▪ Efficiency increases when waste heat is recovered ▪ Can add or remove engines to follow gas recovery trends	▪ Relatively high maintenance costs ▪ Relatively high air emissions ▪ Economics may be marginal areas with low electricity costs	At a minimum, requires primary treatment of LFG; for optimal engine performance, secondary treatment may be necessary
Gas turbine		
▪ Cost per kW of generating capacity drops as the size of the gas turbine 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 ▪ Requires high gas compression ▪ High parasitic loads ▪ Economics may be marginal in areas with low electricity costs	At a minimum, requires primary treatment of LFG; for optimal turbine performance, secondary treatment may be necessary
Microturbine		
▪ Requires lower gas flow ▪ Can function with lower percent methane ▪ Low nitrogen oxides emissions ▪ Relatively easy interconnection ▪ Ability to add and remove units	▪ Economics may be marginal in areas with low electricity costs	Requires fairly extensive primary and secondary treatment of LFG

3.3 Direct Use of Medium-Btu Gas

Figure 3-6. Boiler and Cement Kiln

Boilers, Dryers and Kilns

The simplest and often most cost-effective use of LFG is as a medium-Btu fuel for boiler or industrial processes such as drying operations, kilns, and cement and asphalt production. In these projects, the gas is piped directly to a nearby customer for use in combustion equipment (Figure 3-6) as a replacement or supplementary fuel. Only limited condensate removal and filtration treatment are required, although some modifications of existing combustion equipment might be necessary.

The users' energy requirements are an important consideration in evaluating the sale of LFG for direct use. All gas that is recovered must be used as available, or it is essentially lost, along with associated revenue opportunities, because storing

LFG is not economical. 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, only one piece of equipment (such as a main boiler) or set of burners is dedicated to burning LFG in some facilities. In other cases, a facility might co-fire or blend LFG with other fuels.

Before an LFG energy direct-use project is pursued, LFG flow should be measured, if possible, and gas modeling should be conducted as described in Chapter 2. For more details about project economics, see Chapter 4.

Table 3-6 provides the expected annual LFG flows from landfills of various sizes. While actual LFG flows will vary based on age, composition, moisture and other factors of the waste, these numbers can be used as a first step toward assessing the compatibility of customer gas requirements and LFG output. A rule of thumb for comparing boiler fuel requirements with LFG output is that approximately 8,000 to 10,000 pounds per hour (lb/hr) 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 45,000 lb/hr of steam.

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.

Table 3-6. Potential LFG Flows Based on Landfill Size

Landfill Size (Metric Tons Waste-in-Place)	Annual LFG Flow (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 British thermal units per year   lb/hr: pounds per hour

Equipment modifications or adjustments may be necessary to accommodate the lower Btu value of LFG, and the costs of modifications vary. Costs will be minimal if retuning the boiler burner is the only modification required. The costs associated with retrofitting boilers will vary from unit to unit depending on boiler type, fuel use and age of unit. Retrofitting boilers is typically required in the following situations:

- Incorporating LFG into 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, including retrofit costs (burner modifications, fuel train and process controls), can range from $200,000 to $400,000.
- Modifying a unit that has a surplus or back-up steam supply so that the unit does not rely on the LFG to provide an uninterrupted supply of steam (a loss of LFG pressure can interrupt the steam supply). In this case, manual controls are implemented and the boiler operating system is not integrated into 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. While the gas is not required to have a Btu value as high as pipeline-quality gas, it must be between medium- and high-Btu. This option eliminates the cost of a boiler retrofit and reduces maintenance costs for cleaning deposits associated with the use of medium-Btu LFG.

As described in Section 3.1, Design Factors, 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 typically choose to perform routine cleaning of the boiler tubes. Boiler operators may also choose to install a gas treatment system to reduce the amount of siloxanes in the LFG before it is delivered to the boiler.

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

Examples

The NASA Goddard Flight Center became the first federal facility to burn LFG to meet energy needs.

LFG captured from the Lanchester Landfill in Narvon, Pennsylvania, is used for multiple purposes, including boilers, heaters, thermal oxidizers, ovens, engines and turbines.

For the St. John's LFG Energy Project in Portland, Oregon, LFG provides a stable, competitively priced fuel source for lime kilns. Other benefits include lower utility costs and lower emissions.

In Blythe, Georgia, a Clay Mine LFG Application involves the use of LFG to fuel flash drying operations in the processing of mined clay.

Infrared Heaters

Infrared heating, using LFG as a fuel source, is ideal for facilities with space heating needs that are located near a landfill (Figure 3-7). 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 applications for LFG have been successfully employed at several landfill sites in Europe, Canada and the United States.

Figure 3-7. Infrared Heater

Infrared heaters require a small amount of LFG to operate, are relatively inexpensive, and are easy to install. Current operational projects use between 20 and 50 cubic meters per hour (m^3/hr) (12 to 30 cfm). Infrared heaters do not require pretreatment of the LFG, unless siloxanes are present in the gas. One heater is typically required for every 500 to 800 square feet. Each heater costs approximately $3,000 and the cost of interior piping to connect the heaters within the building ceilings ranges from approximately $20,000 to $30,000.

Greenhouses

LFG can be used to provide heat for greenhouses, power grow lights and heat water used in hydroponic plant cultures (Figure 3-8). The costs for using LFG in greenhouses are highly dependent 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.

Figure 3-8. Greenhouse

Artisan Studios

Artisan studios with energy-intensive activities such as glass-blowing, metalworking and pottery (Figure 3-9) 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.

Figure 3-9. LFG-Powered Glass Studio

Examples

Infrared heaters are used in maintenance facilities at the I-95 Landfill in Virginia.

Several greenhouses have been constructed near landfills to take advantage of the energy cost savings, including the Rutgers University EcoComplex Greenhouse.

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

Leachate Evaporation

Leachate evaporation using LFG, shown in Figure 3-10, is a good option for landfills where leachate disposal at a publicly owned treatment works (POTW) plant is unavailable or expensive. LFG is used to evaporate leachate to a more concentrated and more easily discarded effluent volume (Figure 3-11).

Evaporators are available in sizes to treat 10,000 to 30,000 gallons per day (gpd) of leachate. Capital costs range from $300,000 to $500,000. O&M costs range from $70,000 to $95,000 per year. When a system is owned and operated by a third party, long-term contracts will typically assess costs based on the volume of leachate evaporated. Some economies of scale are realized for larger size vessels, as shown in Table 3-7.

Figure 3-10. Leachate Evaporator

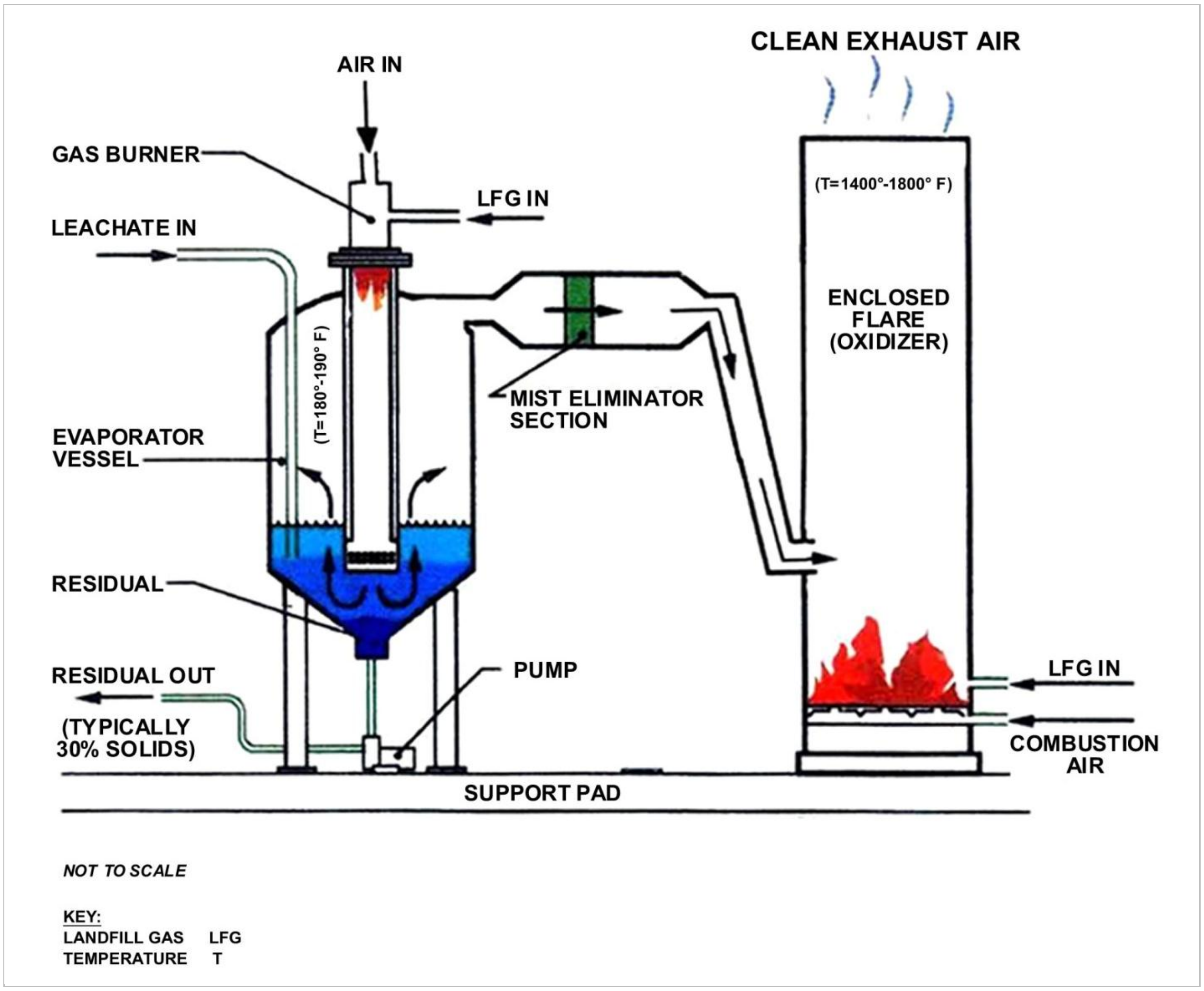
Table 3-7. Cost of Leachate Evaporation[4]

Capacity	Cost
30,000 gpd	$0.05 - $0.06 per gallon
20,000 gpd	$0.09 - $0.12 per gallon
10,000 gpd	$0.18 - $0.20 per gallon

gpd: gallons per day

4 U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

Figure 3-11. Leachate Evaporation Diagram



Biofuel Production

LFG can also be used to heat 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.

Examples

Leachate evaporation is used at the Centralia Landfill in Centralia, Washington, the Cherokee Run Landfill in Bellefontaine, Ohio, and the Fighting Creek Farm Landfill in Coeur d'Alene, Idaho.

One example of an LFG biofuel project is located in Sioux Falls, South Dakota. The Sioux Falls Regional Sanitary Landfill supplies LFG to POET, a producer of biorefined products, for use in a wood waste-fired boiler, which generates steam for use in ethanol production.

Direct Use of Medium-Btu Gas Summary

A summary of the advantages and disadvantages of direct-use technologies is presented in Table 3-8.

Table 3-8. Advantages, Disadvantages and Treatment Requirements Summary (Direct-Use)

Advantages	Disadvantages	Treatment
Boiler, dryer and kiln		
▪ Uses maximum amount of recovered gas flow ▪ Cost-effective ▪ Limited condensate removal and filtration treatment is required ▪ Does not require large amount of LFG and can be blended with other fuels	▪ Cost is tied to length of pipeline; energy user must be nearby	Need to improve quality of gas or retrofit equipment
Infrared heater		
▪ Relatively inexpensive ▪ Easy to install ▪ Does not require a large amount of gas ▪ Can be coupled with another energy project	▪ Seasonal use may limit LFG utilization	Limited condensate removal and filtration treatment
Leachate evaporation		
▪ Good option for landfill where leachate disposal is expensive	▪ High capital costs	Limited condensate removal and filtration treatment

3.4 Conversion to High-Btu Gas

LFG can be used to produce the equivalent of pipeline-quality gas (natural gas), CNG, or LNG, subject to state regulations. Pipeline-quality gas can be injected into a natural gas pipeline used for an industrial purpose. Alternatively, CNG and LNG can also be used to fuel vehicles at the landfill (such as water trucks, earthmoving equipment, light trucks and autos), fuel refuse-hauling trucks (long-haul refuse transfer trailers and route collection trucks), and supply the general commercial market (Figure 3-12). Recent capital costs of high-Btu processing equipment have ranged from $2,600 to $4,300 per scfm of LFG. The annual cost to provide electricity to operate and maintain these systems ranges from $875,000 to $3.5 million.[5] Project costs depend on the purity of the gas required by the receiving pipeline or energy end user as well as the size of the project. Some economies of scale can be achieved when larger quantities of high-Btu gas can be produced.

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

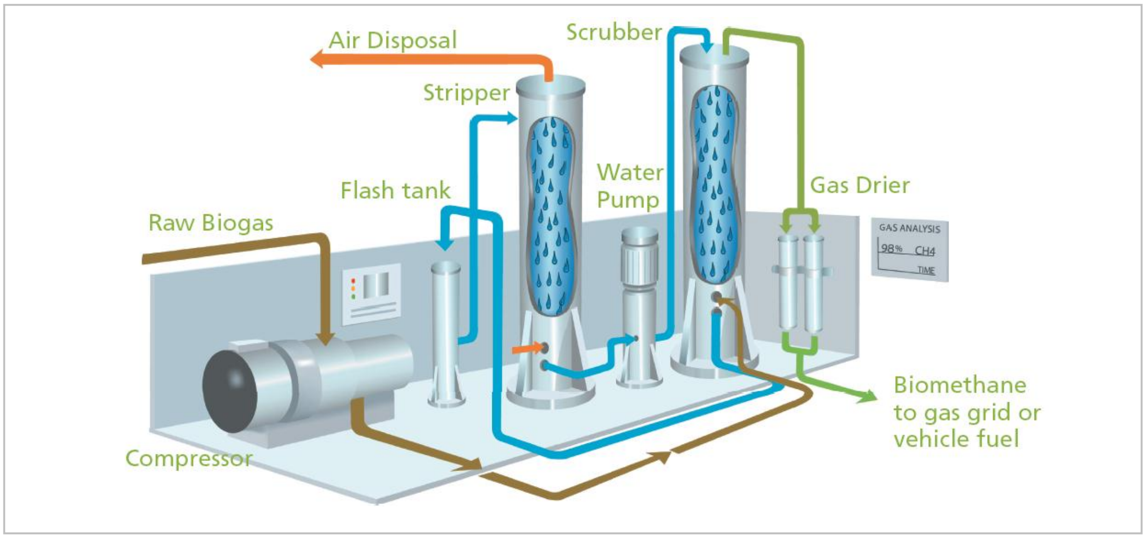
5 U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

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, four methods have been commercially employed (beyond pilot testing) to remove carbon dioxide from LFG:

- ***Water Scrubbing.*** Water scrubbing consists of a high-pressure biogas flow into a vessel column where carbon dioxide and some other impurities, including hydrogen sulfide, are removed by dilution in water that falls from the top of the vessel in the opposite direction of the gas flow. The water scrubbing process is illustrated in Figure 3-13. Methane is not removed because it has less dilution capability. The pressure is set at a point where only the carbon dioxide can be diluted; normally between 110 and 140 pounds per square inch (psi). The water that is used in the scrubbing process is then stripped in a separate vessel to be used again, making this system a closed loop that keeps water consumption low. The gases resulting from the stripping process (the same that were removed from the biogas) are then released or flared. Generally, no chemicals are required for the water scrubbing process, making it an attractive and popular technology.

  It is important to note that this technology will not remove certain contaminants such as oxygen and nitrogen that may be present in the raw biogas. This limitation may be an important variable when the end use of the cleaned gas is considered.

Figure 3-13. Water Scrubbing Unit Flow Schematic[6]



- ***Amine Scrubbing.*** Selexol, a physical solvent that preferentially absorbs gases into the liquid phase, is 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 (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

  The LFG is placed in contact with the Selexol liquid in a Selexol absorber tower. NMOCs are generally hundreds to thousands of times more soluble than methane. Carbon dioxide is about 15

6 American Biogas Council. Biogas Processing for Utilities. February 2012. http://www.americanbiogascouncil.org/biogasProcessing/biogasProcessing.pdf.

times more soluble than methane. Solubility also is enhanced with pressure, facilitating the separation of NMOCs and carbon dioxide from methane.

- ***Molecular Sieve.*** A typical molecular sieve plant employs compression, moisture removal and hydrogen sulfide removal steps, but relies on vapor-phase activated carbon to remove NMOC and a molecular sieve to remove carbon dioxide. Once exhausted, the activated carbon can be regenerated through a depressurizing heating and purge cycle. The molecular sieve process is also known as pressure swing adsorption.
- ***Membrane Separation.*** A typical membrane plant employs compression, moisture removal and hydrogen sulfide removal steps, but relies on activated carbon to remove NMOCs and membranes to remove carbon dioxide. Activated carbon removes NMOCs and protects the membranes. The membrane process takes advantage of the physical property 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.

Air intrusion is the primary cause for the presence of oxygen and nitrogen in LFG and can occur when air is 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 pressure swing adsorption.

Compressed Natural Gas

The membrane separation and molecular sieve processes scale down more economically to smaller plants for CNG production. For this reason, these technologies are more likely to be used for CNG production than the Selexol (amine scrubbing) process. Table 3-9 shows estimated total costs of CNG production for membrane separation processes capable of handling various gas flows. The water scrubbing method also can be used for medium-size projects.

Example

In Winder, Georgia, LFG from the Oak Grove Landfill is processed into pipeline-quality gas for sale to the Municipal Gas Authority of Georgia.

Table 3-9. Cost of CNG Production[7]

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

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

[7] Costs escalated to 2007 dollars from Wheless, E., and others 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.

Examples

The Dane County Bio CNG™ Vehicle Fueling Project located in Dane County, Wisconsin, was recognized as an LMOP 2011 award winner for its successful generation of electricity from landfill methane as well as its use of flared excess LFG to produce CNG that fuels the county's parks and public works department trucks. The system originally produced 100 gallons of gasoline equivalent (GGE) per day and expanded to produce 250 GGE per day in 2013.

St. Laundry Parish in Louisiana was recognized as a 2012 LMOP award winner for its successful LFG-to-CNG project. The Parish converts 50 cubic feet per minute of LFG into 250 GCE of CNG per day. The CNG is used to fuel government vehicles including cars, trucks and vans. Benefits from the project include better air quality and environmental education opportunities for the community.

Liquefied Natural Gas

LNG can be generated from LFG that is first converted to CNG. The CNG produced from LFG is liquefied to produce LNG using conventional natural gas liquefaction technology. When assessing this technology, two factors should be considered:

- Carbon dioxide freezes at a temperature higher than methane liquefies. To avoid "icing" in the plant, the CNG produced from LFG must have the lowest possible level of carbon dioxide. The low carbon dioxide requirement favors a molecular sieve over a membrane separation process, or at least favors upgrading the gas produced by the membrane process with a molecular sieve. Water scrubbing also is an option.
- Natural gas liquefaction plants have generally been "design-to-order" facilities that process large quantities of LNG. A few manufacturers offer smaller, pre-packaged liquefaction plants that have design capacities of 10,000 gpd or greater.

Unless the nitrogen and oxygen content of the LFG is very low, additional steps must be taken to remove nitrogen and oxygen. Liquefier manufacturers desire inlet gas with less than 0.5 percent oxygen, citing explosion concerns. Nitrogen needs to be limited to produce LNG with a methane content of 96 percent. The cost of LNG production is estimated to be $0.65/gallon for a plant producing 15,000 gpd of LNG. A plant producing 15,000 gpd of LNG requires 3,000 scfm of LFG and would require a capital investment approaching $20 million.[8]

Example

In 2009, a high-tech fuel plant was opened in Livermore, California, that demonstrates the viability of LFG as an alternative transportation fuel. LFG processed from the Altamont Sanitary Landfill generates LNG that is used to fuel garbage trucks. More information about the Altamont Landfill Gas to Liquefied Natural Gas Project is available from LMOP's website.

[8] 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.

Conversion to High-Btu Gas Summary

Table 3-10 summarizes the advantages and disadvantages of converting LFG to high-Btu gas.

Table 3-10. Advantages, Disadvantages and Treatment Requirements Summary (High-Btu)

Advantages	Disadvantages	Treatment
Pipeline-quality gas		
▪ Can be sold into a natural gas pipeline	▪ Increased cost that results from tight management of wellfield operation needed to limit oxygen and nitrogen intrusion into LFG	Requires extensive and potentially expensive LFG processing
CNG or LNG		
▪ Alternative fuels for vehicles at the landfill or refuse hauling trucks, and for supply to the general commercial market	▪ Increased cost that results from tight management of wellfield operation needed to limit oxygen and nitrogen intrusion into LFG	Requires extensive and potentially expensive LFG processing

3.5 Selection of Technology

The primary factor in choosing the right project configuration for a particular landfill is the projected expense versus the potential revenue. In general, the most cost-effective option is the sale of medium-Btu gas to a nearby customer, which requires minimal gas processing; costs are typically tied to a retail gas rate rather than an electric buyback rate. If a suitably interested customer is located nearby, 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 wasting gas during 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.

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

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

The most common structure for an LFG electricity project is to sell the electricity to an investor-owned utility, cooperative or municipal entity through a PPA. Typically, the electricity, including energy and capacity, is sold at a fixed price with level of escalation, or at an indexed price based on an estimate of short-run avoided cost, or a publicly available local market price mechanism. Negotiating an acceptable interconnection agreement is important to a successful electric generation project. The interconnection agreement can be a large cost variable and discussions should begin early in the project.

If an electric generation project is selected, the next step is to choose the type of power generation, which depends on the amount of recoverable LFG, the expected quantity for at least 10 years and the gas quality.

If 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. Table 3-11 summarizes the relationship between technology options and the amount of LFG flow available for an LFG energy project.

Table 3-11. Summary of LFG Flow Ranges for Technology Options

Technology	LFG Flow Range (at Approximately 50% Methane)
Electricity	
Internal combustion engine (800 kW to 3 MW per engine)	300 to 1,100 cfm; multiple engines can be combined for larger projects
Gas turbine (1 to 10 MW per gas turbine)	Exceeds minimum of 1,300 cfm; typically exceeds 2,100 cfm
Microturbine (30 to 250 kW per microturbine)	20 to 200 cfm
Direct Use Medium-Btu	
Boiler, dryer and process heater	Utilizes all available recovered gas
Infrared heater	Small quantities of gas, as low as 20 cfm
Greenhouse	Small quantities of gas
Artisan studio	Small quantities of gas
Leachate evaporation	1,000 cfm is necessary to treat 1 gallon per minute of leachate
Direct Use High-Btu	
Pipeline-quality gas	600 cfm and up, based on currently operating projects
CNG or LNG	Depends on project-specific conditions

cfm: cubic feet per minute CNG: compressed natural gas kW: kilowatt
LNG: liquefied natural gas MW: megawatt

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

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

For more information about project economics and financing, see Chapter 4.
For more information about permitting requirements and relevant regulations, see Chapter 5.

4. Project Economics and Financing

Evaluating the economic feasibility of an LFG energy project is an essential step and should be completed before preparing a system design, entering into contracts or purchasing materials and equipment. The process for evaluating project alternatives and financing options is discussed in this chapter, highlighting:

- Typical capital and O&M costs and influential factors
- Potential revenue streams, financial incentives and funding opportunities
- Preliminary financial evaluations
- Project financing options

The evaluation process begins with a preliminary economic feasibility assessment.[1] If the preliminary assessment shows that a project may be well-suited to the landfill, then a detailed economic assessment should be performed. The detailed economic assessment, which usually requires assistance from a qualified LFG professional engineering consultant or project developer, is tailored to the landfill and considers potential project options.

LMOP provides *LFGcost-Web* as a tool for conducting initial economic feasibility analyses for 12 types of LFG energy projects. The tool provides economic analyses and environmental benefits based on user inputs.

Both the preliminary and detailed economic feasibility assessments follow the same steps, but they are based on different cost estimates. Preliminary economic feasibility studies are based on *typical* costs. Detailed feasibility studies apply *project-specific* costs and estimates, such as cost quotes for a specific model of equipment appropriate to the landfill, right-of-way costs for anticipated pipeline routes and current land owners, state-specific permitting requirements, specific financing methods, and interest rates. In both cases, the outputs of the economic assessment include costs and measures of financial performance required to make investment decisions, including:

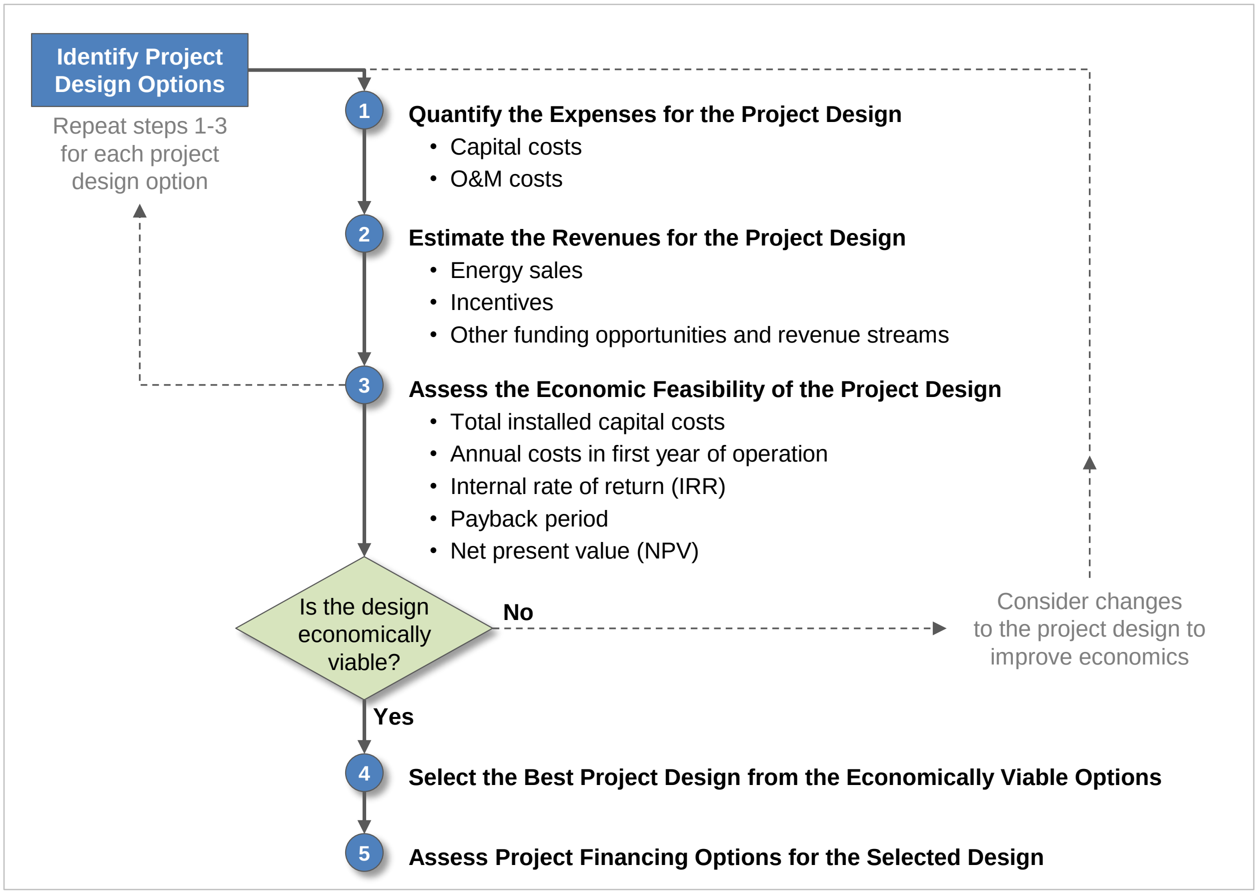
- Total installed capital costs
- Annual costs in first year of operation
- Internal rate of return (IRR)
- Payback period
- Net present value (NPV)

This chapter is relevant for both preliminary and detailed economic feasibility assessments.

1 The cost summaries and example energy cost estimates that are presented in this chapter were calculated using *LFGcost-Web*, Version 2.2.

Figure 4-1 illustrates the economic assessment process, which typically involves five steps. The following sections describe the 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

Generally, the costs for LFG energy projects involve the purchase and installation of equipment (capital costs) and O&M costs. Cost elements common to various types of LFG energy projects are listed below.

Table 4-1. Capital and O&M Cost Elements

Capital Costs Elements	O&M Cost Elements
▪ Design and engineering	▪ Parts and materials
▪ Permits and fees	▪ Labor
▪ Site preparation and installation of utilities	▪ Utilities
▪ Equipment, equipment housing and installation	▪ Financing costs
▪ Startup costs and working capital	▪ Taxes
▪ Administration	▪ Administration

The following sections describe specific factors that may influence the costs of gas collection and flaring, electricity generation, direct use or other project options.

Gas Collection System and Flaring Costs

All LFG energy project designs include a gas collection and flare system to collect the LFG for use in electricity-generating equipment or direct-use devices. The flare system also provides a means of combusting the gas when the project is not being operated. A mid-sized LFG collection and flare system for a 40-acre wellfield designed to collect 600 cfm is approximately $1,022,000, or $25,500 per acre for installed capital costs (2013 dollars), with average annual O&M costs of around $180,000 or $4,500 per acre.[2] These costs can vary depending on several design variables of the gas collection system. The components and key factors that influence the costs of the gas collection and flare system are listed in Table 4-2.

Table 4-2. Gas Collection and Flare System Components and Cost Factors

Component / Attribute	Key Site-Specific Factors
Gas collection wells or connectors	▪ Area and depth of waste ▪ Spacing of wells or connectors
Gas piping	▪ Gas flow volume ▪ Length of piping required
Condensation knockout drum	▪ Volume of drum required
Blower	▪ Size of blower required
Flare	▪ Type of flare (open, ground or elevated) ▪ Size of flare
Instrumentation and control system	▪ Types of controls required

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 install a relatively small collection system first and then expand the system as additional areas of the landfill 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 (such as a blower) is temporarily out of service. However, such an approach might limit economies of scale.

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 is already in operation, it represents a "sunk" cost, and the project costs should include only the costs necessary to modify the system to retrofit the LFG energy project design.

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. 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. If there is a use for the waste heat produced from the combustion of the LFG in the electricity-generating equipment, then a CHP project may be a preferable option.

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2 U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

Table 4-3 lists some typical costs and applicable LFG energy project sizes for the most common electricity generation technologies. The costs include electricity generation equipment and typical compression and treatment systems appropriate to the particular technology and interconnection equipment.

Internal combustion engines cannot operate with LFG volumes that are much lower than the designed target. When the volume is too small, efficiency rates decrease significantly. As a result, oversizing equipment of this type should be avoided.

Table 4-3. LFG Electricity Project Technologies — Cost Summary[3]

Technology	Optimal Project Size Range	Typical Capital Costs ($/kW)*	Typical Annual O&M Costs ($/kW)*
Microturbine	1 MW or less	$2,800	$230
Small internal combustion engine	799 kW or less	$2,400	$220
Large internal combustion engine	800 kW or greater	$1,800	$180
Gas turbine	3 MW or greater	$1,400	$130

$/kW: dollars per kilowatt kW: kilowatt MW: megawatt
*2013 dollars for typical project sizes

Engine size is a key factor to consider because LFG flow rate changes over the life of the project. It is important to decide whether to choose equipment for minimum flow, maximum flow or average flow rates. Because of 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. However, smaller capacity engines may not be able to maximize the opportunity to generate electricity and receive revenues in years when gas is most plentiful. System components and key factors that influence the feasibility of an electricity project are presented in Table 4-4.

Table 4-4. Electricity Generation System Components and Cost Factors

Component / Attribute	Key Site-Specific Factors
Engine size	▪ Flow rate (gas curve) ▪ Electricity rate structures ▪ Minimum electricity generation requirements (contract obligations)
Capacity to expand	▪ Maximum flow rate ▪ Gas flow volume over time (gas curve)
Gas compression and treatment equipment	▪ Quality of the LFG (methane content) ▪ Contaminants (for example, siloxane, hydrogen sulfide)
Interconnection equipment	▪ Project size ▪ Local utility requirements and policies

For more information on interconnection, see the EPA CHP Partnership's Interconnection Standards webpage.

3 U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

Examples of preliminary economic assessments are presented in Table 4-5. These examples, generated from the *LFGcost-Web* tool, are based on a 3 MW internal combustion engine project with a 15-year lifetime and show the typical inputs, assumptions and outputs expected from a preliminary economic assessment.

Table 4-5. Example Preliminary Assessment Results for an Electricity Project[4]

No.	Project Description	Financing and Revenue Elements	Financial Results Summary*
Privately Developed Projects (Marginal tax rate = 35%)			
1	▪ 3 MW engine project ▪ Excludes LFG collection and flaring system costs	▪ 20% down payment, 80% financed ▪ 6% interest rate, 8% discount rate ▪ 6¢/kWh (default) electricity price	▪ Capital cost: $5,306,874 ▪ O&M cost: $566,786 ▪ NPV: $943,413 ▪ IRR: 14% ▪ NPV payback (years): 12
2	▪ 3 MW engine project ▪ Includes LFG collection and flaring system costs	▪ 20% down payment, 80% financed ▪ 6% interest rate, 8% discount rate ▪ 6¢/kWh (default) electricity price	▪ Capital cost: $7,679,300 ▪ O&M cost: $908,710 ▪ NPV: ($3,311,713) ▪ IRR: -7% ▪ NPV payback (years): None
3	▪ 3 MW engine project ▪ Includes LFG collection and flaring system costs	▪ 20% down payment, 80% financed ▪ 6% interest rate, 8% discount rate ▪ 8.24¢/kWh electricity price calculated to achieve 8% IRR	▪ Capital cost: $7,679,300 ▪ O&M cost: $936,999 ▪ NPV: $9,483 ▪ IRR: 8% ▪ NPV payback (years): 15
4	▪ 3 MW engine project ▪ Includes LFG collection and flaring system costs	▪ 20% down payment, 80% financed ▪ 6% interest rate, 8% discount rate ▪ 6¢/kWh (default) electricity price ▪ $2/metric ton carbon dioxide equivalent credit revenue included	▪ Capital cost: $7,679,300 ▪ O&M cost: $908,710 ▪ NPV: ($1,151,383) ▪ IRR: 3% ▪ NPV payback (years): None
5	▪ 3 MW engine project ▪ Excludes LFG collection and flaring system costs	▪ 20% down payment, 80% financed ▪ 6% interest rate, 8% discount rate ▪ 6¢/kWh (default) electricity price ▪ 2¢/kWh renewable energy credit included	▪ Capital cost: $5,306,874 ▪ O&M cost: $566,786 ▪ NPV: $3,284,921 ▪ IRR: 29% ▪ NPV payback (years): 5
Municipality Developed Projects (Marginal tax rate = 0%)			
6	▪ 3 MW engine project ▪ Excludes LFG collection and flaring system costs	▪ 100% down payment using municipal budget ▪ 5% discount rate ▪ 6¢/kWh (default) electricity price	▪ Capital cost: $5,306,874 ▪ O&M cost: $566,786 ▪ NPV: $3,660,118 ▪ IRR: 14% ▪ NPV payback (years): 8
7	▪ 3 MW engine project ▪ Excludes LFG collection and flaring system costs	▪ 20% down payment, 80% bond-financed ▪ 5% interest rate, 5% discount rate ▪ 6¢/% kWh (default) electricity price	▪ Capital cost: $5,306,874 ▪ O&M cost: $566,786 ▪ NPV: $3,457,951 ▪ IRR: 22% ▪ NPV payback (years): 7

4 U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

No.	Project Description	Financing and Revenue Elements	Financial Results Summary*
8	▪ 3 MW engine project ▪ Includes LFG collection and flaring system costs	▪ 100% down payment using municipal budget ▪ 5% discount rate ▪ 6¢/kWh (default) electricity price	▪ Capital cost: $7,679,300 ▪ O&M cost: $908,710 ▪ NPV: ($2,672,918) ▪ IRR: -1% ▪ NPV payback (years): None
9	▪ 3 MW engine project ▪ Includes LFG collection and flaring system costs	▪ 20% down payment, 80% bond-financed ▪ 5% interest rate, 5% discount rate ▪ 6¢/kWh (default) electricity price	▪ Capital cost: $7,679,300 ▪ O&M cost: $908,710 ▪ NPV: ($2,965,463) ▪ IRR: -6% ▪ NPV payback (years): None
10	▪ 3 MW engine project ▪ Includes LFG collection and flaring system costs	▪ 20% down payment, 80% bond-financed ▪ 5% interest rate, 5% discount rate ▪ 7.25¢/kWh electricity price calculated to achieve 5% IRR	▪ Capital cost: $7,679,300 ▪ O&M cost: $924,496 ▪ NPV: $6,634 ▪ IRR: 5% ▪ NPV payback (years): 15

IRR: internal rate of return — kWh: kilowatt-hour — MW: megawatt
NPV: net present value — O&M: operation and maintenance
*2013 dollars for capital costs and NPV in year of construction and 2014 dollars for O&M costs in initial year of engine operation

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 or furnaces; or space heating for commercial, industrial or institutional facilities or for greenhouses. Table 4-6 lists typical cost ranges for the components of a direct-use project. The costs 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. The gas pipeline costs also assume typical construction conditions and pipeline design.

Table 4-6. LFG Direct-Use Project Components — Cost Summary[5]

Component	Typical Capital Costs*	Typical Annual O&M Costs*
Gas compression and treatment	$1,100/scfm	$130/scfm
Gas pipeline and condensate management system	$347,000/mile	Negligible

scfm: standard cubic feet per minute — *2013 dollars, based on a 1,000 scfm system

Costs for direct-use projects vary depending on the end user's requirements and the size of the pipelines. For example, costs will be higher if more extensive treatment is required to remove other impurities. Pipelines can range from less than a mile to more than 30 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. The size of the pipeline also can affect project costs. It is often most cost-effective for projects with increasing gas flow over time 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 4-7 highlights the direct-use system components and key factors that influence the feasibility of a project.

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[5] U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

Table 4-7. Direct-Use Project Components and Cost Factors

Component / Attribute	Key Site-Specific Factors
End use of the LFG	▪ Type of equipment (for example, boiler, process heater, kiln furnace) ▪ Gas flow over time ▪ Requirements to modify existing equipment to use LFG
Gas compression and treatment equipment	▪ Quality of the LFG (methane content) ▪ Contaminants and moisture removal requirements ▪ Filtration requirements
Gas pipeline	▪ Length (distance to the end use) ▪ Obstacles along the pipeline route ▪ Gas flow volume
Condensate management system	▪ Length of the gas pipeline

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 the combustion device. Landfill owners or LFG energy project developers may need to inform the end users that they are responsible for paying for these modifications, noting that modification costs are normally minimal and that the savings typically achieved by using LFG will make up for equipment modification expenses.

LMOP developed the fact sheet Adapting Boilers to Utilize Landfill Gas: An Environmentally and Economically Beneficial Opportunity to help potential end users understand the types of modifications that may be needed to use LFG. The fact sheet also provides several examples of where LFG has been used in boiler fuel applications.

Example preliminary economic assessments for a typical direct-use project (in this case, 1,000 scfm LFG) with either a 5- or 10-mile pipeline and a 15-year lifetime are presented in Table 4-8. These examples provide ideas about typical inputs, assumptions and outputs expected from a preliminary economic assessment.

Table 4-8. Example Preliminary Assessment Results for Direct-Use Projects[6]

No.	Project Description	Financing and Revenue Elements	Financial Results Summary*
Privately Developed Projects (Marginal tax rate = 35%)			
1	▪ Direct-use project with 5-mile pipeline (includes condensate management) ▪ Excludes LFG collection and flaring system costs	▪ 20% down payment, 80% financed ▪ 6% interest rate, 8% discount rate ▪ $3.50/MMBtu LFG price	▪ Capital cost: $2,864,002 ▪ O&M cost: $133,228 ▪ NPV: $2,136,288 ▪ IRR: 33% ▪ NPV payback (years): 5
2	▪ Direct-use project with 5-mile pipeline (includes condensate management) ▪ Includes LFG collection and flaring system costs	▪ 20% down payment, 80% financed ▪ 6% interest rate, 8% discount rate ▪ $3.50/MMBtu LFG price	▪ Capital cost: $5,236,428 ▪ O&M cost: $494,095 ▪ NPV: ($1,976,668) ▪ IRR: -5% ▪ NPV payback (years): None

6 U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

No.	Project Description	Financing and Revenue Elements	Financial Results Summary*
3	▪ Direct-use project with 10-mile pipeline (includes condensate management) ▪ Excludes LFG collection and flaring system costs	▪ 20% down payment, 80% financed ▪ 6% interest rate, 8% discount rate ▪ $3.50/MMBtu LFG price	▪ Capital cost: $4,598,169 ▪ O&M cost: $133,228 ▪ NPV: $972,702 ▪ IRR: 15% ▪ NPV payback (years): 11
4	▪ Direct-use project with 10-mile pipeline (includes condensate management) ▪ Includes LFG collection and flaring system costs	▪ 20% down payment, 80% financed ▪ 6% interest rate, 8% discount rate ▪ $3.50/MMBtu LFG price	▪ Capital cost: $6,970,594 ▪ O&M cost: $494,095 ▪ NPV: ($3,545,933) ▪ IRR: -10% ▪ NPV payback (years): None
Municipality-Developed Projects (Marginal tax rate = 0%)			
5	▪ Direct-use project with 5-mile pipeline (includes condensate management) ▪ Excludes LFG collection and flaring system costs	▪ 100% down payment using municipal budget ▪ 5% discount rate ▪ $3.50/MMBtu LFG price	▪ Capital cost: $2,864,002 ▪ O&M cost: $133,228 ▪ NPV: $5,136,381 ▪ IRR: 25% ▪ NPV payback (years): 5
6	▪ Direct-use project with 5-mile pipeline (includes condensate management) ▪ Excludes LFG collection and flaring system costs	▪ 20% down payment, 80% bond-financed ▪ 5% interest rate, 5% discount rate ▪ $3.50/MMBtu LFG price	▪ Capital cost: $2,864,002 ▪ O&M cost: $133,228 ▪ NPV: $5,027,276 ▪ IRR: 51% ▪ NPV payback (years): 3
7	▪ Direct-use project with 5-mile pipeline (includes condensate management) ▪ Includes LFG collection and flaring system costs	▪ 100% down payment using municipal budget ▪ 5% discount rate ▪ $3.50/MMBtu LFG price	▪ Capital cost: $5,236,428 ▪ O&M cost: $494,095 ▪ NPV: ($1,446,148) ▪ IRR: 0% ▪ NPV payback (years): None
8	▪ Direct-use project with 5-mile pipeline (includes condensate management) ▪ Includes LFG collection and flaring system costs	▪ 20% down payment, 80% bond-financed ▪ 5% interest rate, 5% discount rate ▪ $3.50/MMBtu LFG price	▪ Capital cost: $5,236,428 ▪ O&M cost: $494,095 ▪ NPV: ($1,645,631) ▪ IRR: -4% ▪ NPV payback (years): None

IRR: internal rate of return NPV = net present value
MMBtu = million British thermal units O&M = operation and maintenance
*2013 dollars for capital costs and NPV in year of construction and 2014 dollars for O&M costs in initial year of engine operation

Other Project Options

Other LFG energy project options include CHP, leachate evaporation, vehicle fuel and upgrading to high-Btu gas. These technologies are not as universally applicable as the more traditional electricity and direct-use LFG energy projects, but they can be very cost-effective options for some landfills.

- ***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 LFG collected. 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 are generated at the site. The electricity produced by the end user can be used on site or sold to the grid.

- ***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 POTW or wastewater treatment plant is unavailable or very expensive.
- ***Vehicle Fuel Applications*** involve the production of CNG, LNG or methanol. This process involves removing carbon dioxide and trace impurities from LFG to produce a high-grade fuel that is approximately 95 percent methane or greater. 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 at present. However, as interest in alternative fuels continues to grow, demand is expected to increase. Furthermore, landfill owners and 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.
- ***Upgrading to High-Btu Gas Technologies*** 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. These projects are ideally suited for large landfills located near natural gas pipelines.

For more information on CHP, see EPA's CHP Partnership website.
For more information on technologies for upgrading LFG to high-Btu gas, see Chapter 3.

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

Electricity Project Revenues

The primary revenue source for typical electricity projects is the sale of electricity to a local utility or private user. Revenue potential is affected by the electricity buy-back rates (the rate at which the local utility purchases electricity generated by the LFG energy project), which depend on several factors specific to the local electric utility and the type of contract available to the project. Buy-back rates typically range from 2.5 to 11 cents per kilowatt-hour (kWh).[7, 8, 9] The upper end of this range represents premium pricing for renewable electricity. Occasionally, the electricity is sold to a third party (private user) at a rate that is attractive when compared with the local retail electricity rates.

It is important to consider the amount of electricity generated from the LFG that the landfill will use directly to support on-site operations. These "avoided" electricity costs are, in effect, the costs of the electricity that the landfill does not have to purchase from a utility. Avoided electricity is not valued at the buy-back rate, but at the rate the landfill is charged to purchase electricity (the retail rate). The retail rate is often significantly higher than the buy-back rate.

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7 RFP No. 10005 Power Purchase from Small Renewable Electric Generation Project(s), Nebraska Public Power District, Attachment 4: NPPD System Cost Information. April 1, 2010.

8 U.S. DOE Energy Information Administration. 2013. Average Wholesale Price Tables. http://www.eia.doe.gov/cneaf/electricity/wholesale/wholesale.html

9 Orange County Register, "Turning Trash into Power for 22,000 Homes," January 21, 2011. http://articles.ocregister.com/2011-01-21/news/27045525_1_power-plant-plant-s-proximity-trash-to-electricity

LFG is recognized as a renewable, or "green," energy resource, so additional revenues may be available through premium pricing, tax credits, GHG credit trading or incentive payments. These revenues can be reflected in an economic analysis in various ways, but converting to a cents/kWh format is typically most useful.

The *LFGcost-Web* economic feasibility assessment tool accommodates several common types of electric project credits including a direct cash grant, a GHG reduction credit expressed in dollars per metric ton of carbon dioxide equivalent, a renewable electricity credit expressed in dollars per kWh, and a renewable fuel credit expressed in dollars per gallon.

- Premium pricing is often available for renewable electricity (including LFG) that is included in a green power program, through an RPS, a Renewable Portfolio Goal (RPG), or a voluntary utility green pricing program. The LMOP Funding Guide provides more details about state RPS and RPG resources that apply to LFG energy projects. 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.

- RECs are sold through voluntary markets to consumers seeking to reduce their environmental footprint. They are typically offered in 1 MWh units, and are sold by LFG electricity generators to industries, commercial businesses, institutions and 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. EPA's Green Power Partnership provides a state-by-state directory of green power providers in the Green Power locator.

- Tax credits, tax exemptions and other tax incentives, as well as federal and state grants, low-cost bonds and loan programs, may provide funding resources for an LFG energy project. For example, Section 45 of the Internal Revenue Code provides a 1.1 cent per kWh production tax credit for electricity generated at privately owned LFG electricity projects. A 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 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 the LMOP Funding Guide.

- Many state and regional government entities are establishing their own GHG and renewable energy initiatives. For comprehensive and up-to-date information about state and regional incentives and policies for renewable energy resources, including LFG, visit the Database of State Incentives for Renewables and Efficiency (DSIRE) website.

- LFG is considered an advanced biofuel under the Renewable Fuel Standard (RFS) program. Administered by EPA, the program requires obligated parties (such as refiners, blenders and importers) to meet a renewable volume obligation (RVO) based on the amount of conventional fuels handled annually. In July 2014, the EPA issued a final rule for RFS Pathways II. This ruling qualifies CNG and LNG produced from LFG, and electricity produced from LFG to power electric vehicles as cellulosic and advanced fuel pathways. EPA uses a Renewable Identification Number (RIN) to track compliance and developed an electronic transaction system (EPA Moderated Transaction System) to allow RIN generators and regulated parties to conduct RIN transactions. If an RVO party has access to RINs, it can sell those RINs on the open market. Conversely, if an obligated party cannot or does not wish to

For LFG (biogas), 77,000 Btu is equal to 1 gallon equivalent or 1 RIN.

blend renewable fuels into conventional fuel and, therefore, does not have enough RINs to meet its RVO, it can purchase RINs from other entities. Over time, EPA will raise the renewable volume requirements, which may offer a growing market for LFG.

- Some LFG energy projects may qualify for participation in nitrogen oxides cap-and-trade programs. 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 the end use of the LFG. CHP projects typically receive more revenue based on credit for avoided use as boiler fuel. See the EPA document Environmental Revenue Streams for Combined Heat and Power for additional information.

- Bilateral trading and GHG credit sales are other voluntary sources of revenue. Bilateral trades are project-specific and are negotiated directly between a buyer and seller of GHG 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 a means to develop their own project. Therefore, a buyer may help finance a specific project in exchange for the credit of offsetting GHG emissions from their organization. These projects may be simple transactions between a single buyer and seller (for example, the project developer), or may involve brokers that "aggregate" credits from several small projects for sale to large buyers. Bilateral trading programs often involve certification and quantification of GHG reductions to ensure the validity of the trade and, as a result, there can be rigorous monitoring and recordkeeping requirements. The additional revenue is likely to justify these additional efforts.

Example

Golden Triangle Regional Solid Waste Management Authority Power Generation Project, Mississippi. Golden Triangle staff spent several years evaluating LFG energy project possibilities and seeking solutions to overcome challenges associated with the site's remote location, lack of nearby potential end users and projected high installation costs. In 2010, Golden Triangle arranged an agreement with the Tennessee Valley Authority's Generation Partners program to secure premium green power prices for the LFG energy. Within 1 year, the project became the first LFG electricity project in Mississippi, generating just under 1 MW of renewable energy.

Direct-Use Project Revenues

The primary source of revenue for direct-use projects is the sale of LFG to the end user, so the price of LFG determines project revenues. Often, LFG sales prices are indexed to the price of natural gas (for example, 70 percent of the New York Mercantile Exchange (NYMEX) or Henry Hub natural gas price indices), but prices will vary depending on site-specific negotiations, the type of contract and other factors.

The Henry Hub, the largest centralized point for natural gas spot and futures trading in the United States, interconnects nine interstate and four intrastate pipelines. The Henry Hub is owned and operated by Sabine Pipe Line, LLC, a wholly owned subsidiary of ChevronTexaco. The Sabine Pipe Line starts near Port Arthur, Texas, and ends in Vermillion Parish, Louisiana, at the Henry Hub near the town of Erath.

NYMEX, the world's largest physical commodity futures exchange, uses the Henry Hub as the point of delivery for its natural gas futures contract. The NYMEX gas futures contract began trading on April 3, 1990, and is currently traded 72 months into the future. NYMEX deliveries at the Henry Hub are treated in the same way as cash-market transactions.

In recent years, due to the decline of natural gas prices from roughly $13 per MMBtu in 2008 to $5 per MMBtu in 2013, typical LFG prices have ranged from $1.50 to $4.00 per MMBtu.[10]

Federal and state tax incentives, loans and grants are available that may provide additional revenue for direct-use projects. The LMOP Funding Guide presents updated information on available incentives and how to qualify for them. Renewable energy tax credits, for LFG or high-Btu utilization and electricity generation, may be available to private entities that pay taxes.

EPA conducts legislative analysis to examine the environmental and economic effects of pending legislation and new climate change programs. For example, legislation may change the applicability of offset credits or redefine eligibility requirements for tax credits or incentives. New programs also may offer grant programs or otherwise affect factors that influence project revenues. Visit EPA's Legislative Analysis webpage for more information.

4.3 Step 3: Assess Economic Feasibility

Once the costs and revenues for a project have been determined, and the project is considered technically viable, an economic feasibility analysis should be performed. Project developers can use *LFGcost-Web* to evaluate the preliminary economic feasibility. When a more detailed analysis is undertaken, 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.

A 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 the analysis, calculate and compare the expenses and revenue on a year-by-year basis for the life of the project. The following elements should be included, most of which can be obtained from *LFGcost-Web* (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 financed, interest rate, cost to service the debt each year
- Inflation rates (can alter O&M costs, especially if the product is sold at a fixed price over a term)
- Product price escalation rates — increases or decreases in the price of electricity or LFG
- Revenue calculation — sales of electricity and other revenue from incentives and markets
- Risk sensitivity and cost uncertainty factors — unpredictable conditions that affect project operations and increasing or decreasing capital or O&M costs
- Tax considerations — applicable taxes or tax credits that affect revenue streams

A *pro forma* analysis will calculate measures of economic performance that are used to assess financial feasibility, such as:

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

[10] U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

- ***NPV at year of construction*** — Value of the project at the first year that is equivalent to all the cash flows, based on the discount rate. This amount 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 value is the number of years for the project to pay for itself.
- ***Annual cash flow* —** Total revenue from the project minus expenses, including O&M and capital amortization costs. Essentially this measure represents the income the project generates in a year.

For preliminary assessments, *LFGcost-Web* 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.

A combination of financing factors contributes to the lifetime project cost. For example, loan periods, interest rates and down payment requirements affect the overall cost of lender financing (if a loan is used to pay for the project). If municipal bonds are issued to fund the project, the discount rate affects how much a bond must yield when due. Taxes will also affect how much revenue is generated (the, 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.

Table 4-9 provides an example of a preliminary analysis of economic feasibility. The results shown are based on four examples presented in Tables 4-5 and 4-8. These cases assume the landfill does not have an existing gas collection and flaring system. The "private" columns illustrate results for a privately owned landfill or for instances where a private developer implements a project at a municipal landfill.

Table 4-9. Example Financial Performance Indicators for Projects without an Existing Gas Collection and Flare System[11]

Economic Performance Parameter	3 MW Engine Project (With Gas Collection and Flaring System Costs)*		Direct-Use Project (1,000 scfm) (5 Mile — With Gas Collection and Flaring System Costs)*	
	Private[a]	Municipal[b]	Private[c]	Municipal[d]
Net present value (NPV)**	($3,311,713)	($2,965,463)	($1,976,668)	($1,645,631)
Internal rate of return (IRR)	-7%	-6%	-5%	-4%
NPV payback period (years)	None		None	
Capital costs**	$7,679,300		$5,236,428	
O&M costs**	$908,710		$494,095	

* Electricity sale price is 6¢/kWh (engine projects); LFG price is $3.50/MMBtu (direct-use projects).
** 2013 dollars for capital costs and NPV in year of construction; 2014 dollars for O&M costs (initial year of engine operation).
[a] 20% down payment, 6% interest rate, 8% discount rate. See example 2 from table 4-5.
[b] 20% down payment, 80% municipal bond, 5% interest rate, 5% discount rate. See example 9 from table 4-5.
[c] 20% down payment, 6% interest rate, 8% discount rate. See example 2 from table 4-8.
[d] 20% down payment, 80% municipal bond, 5% interest rate, 5% discount rate. See example 8 from table 4-8.

[11] U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

Based on these results, neither the direct-use project nor the engine project initially presents an attractive option. However, the electricity project may qualify for various GHG credit programs because it includes installation of a new LFG collection system that will directly reduce methane emissions. If the collection system was installed voluntarily and meets other criteria, the additional revenues available from GHG credits may significantly improve the economic viability of this project option. To illustrate how credits or incentives could change the results of the analysis, consider the following:

- Applying a $2/metric ton carbon dioxide equivalent credit (which may or may not reflect the current market price) to this engine project would yield an additional $330,000 per year on average, resulting in additional revenue of nearly $5 million over the 15-year life of the project. The credit increases the IRR for the private 3 MW engine project up to a positive value of 3 percent. This scenario is presented as example 4 in Table 4-5.
- If the electricity sales revenue could be increased to 8.24¢/kWh instead of 6¢/kWh through a green power program or sale of RECs, then the IRR for the private 3 MW engine project would increase to a positive 8 percent. This scenario is presented as example 3 in Table 4-5.

LFG energy projects in which a gas collection and flaring system is already in place realize improved economics because the installation costs for the collection system are not attributed to the energy project. Instead, the costs for gas collection are considered a “sunk” cost associated with other landfill operations, such as mitigating methane migration or controlling odors. However, these projects will generally not be eligible for credits for GHG capture if the gas collection and flaring was required by regulatory programs. Table 4-10 presents examples where an LFG collection and flaring system is already in place.

Table 4-10. Example Financial Performance Indicators for Projects with a Gas Collection and Flare System in Place[12]

Economic Performance Parameter	3 MW Engine Project (Without Gas Collection and Flaring System Costs)*		Direct-Use Project (5 Mile — Without Gas Collection and Flaring System Costs)*	
	Private[a]	Municipal[b]	Private[c]	Municipal[d]
Net present value (NPV)**	$943,413	$3,457,951	$2,136,288	$5,027,2761
Internal rate of return (IRR)	14%	22%	33%	51%
NPV payback period (years)	12	7	5	3
Capital costs**	$5,306,874		$2,864,002	
O&M costs**	$566,786		$133,228	

* Electricity sale price is 6¢/kWh (engine projects); LFG price is $3.50/MMBtu (direct-use projects).
** 2013 dollars for capital costs and NPV in year of construction and 2014 dollars for O&M costs in initial year of engine operation.
[a] 20% down payment, 6% interest rate, 8% discount rate. See example 1 from table 4-5.
[b] 20% down payment, 80% municipal bond, 5% interest rate, 5% discount rate. See example 7 from table 4-5.
[c] 20% down payment, 6% interest rate, 8% discount rate. See example 1 from table 4-8.
[d] 20% down payment, 80% municipal bond, 5% interest rate, 5% discount rate. See example 6 from table 4-8.

The assumption that the collection and flaring system is already installed makes each option viable. The direct-use projects appear more favorable, but finding a suitable end user within a reasonable distance is not always possible. Assuming additional revenue from premium pricing on electricity, the internal combustion engine case becomes considerably more advantageous. For example, applying a 2¢/kWh

[12] U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

credit on top of the buy-back rate increases the IRR for the private 3 MW internal combustion engine to 29 percent, with a payback of 5 years. This scenario is presented as example 5 in Table 4-5.

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 quickly recover the capital investment in only a couple of years. The financial requirements of the parties involved in developing a project must be considered in evaluating 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 Chapter 5 and Chapter 6 for more information on project structures and development options.

4.4 Step 4: Compare All Economically Feasible Options and Select Winners

After the initial economic analysis for each project option has been completed, a comparison should be made to decide which one best meets the project objectives. After the comparison, 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 likely, however, that multiple energy project options are viable, and it may be necessary to compare the economic analysis of each to select the most promising option, bearing in mind any non-price factors as discussed below.

A side-by-side 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 acceptable. Results may show that the project with the highest IRR has capital and O&M costs that exceed available financing. If so, a lower IRR project that costs less and is easier to finance may be the best option.

Conducting a sensitiveness analysis can help the project developer understand the risks associated with different scenarios. For example, projects that carry lower risks can be more attractive to investors even if IRRs are higher because of the level of risk each one presents for certain factors. If a specific risk is identified, the investor or developer can use financial operations, such as hedging, to mitigate certain (but not all) risks.

At this point, important non-price factors should be considered, such as risks related to the attainment of emissions limits or the use of new technology. Non-price factors that affect the project may not be quantifiable by the economic analysis. 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 obtain a permit for a new combustion device. In this case, finding a direct user that could supplant some of its current fuel use with LFG might be a more viable project. In another example, project options that use proven technologies may incur lower risk than options using newer technologies. The new technologies might offer the potential for a greater return on investment, but the risk may influence the financing available and may result in 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. To begin, it is helpful to understand what lenders and investors expect.

What Lenders and Investors Expect

Typically, lenders and project investors examine the anticipated financial performance to decide whether or not to support a project. The debt coverage ratio is an important measure that the lender or 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 debt 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 the 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 4-11 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 4-11. 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 and warranties
Equipment performance	▪ Select proven technology for proposed energy use ▪ Design LFG treatment system to remove impurities, as necessary ▪ Get performance guarantees and warranties from vendor ▪ Include major equipment vendor as partner ▪ Select qualified operator
Environmental planning	▪ Obtain permits before financing (air, water and building) ▪ Plan for condensate disposal
Community acceptance	▪ Obtain zoning approvals ▪ Demonstrate community support

Risk Category	Risk Mitigation Measure
Power sales agreements (PSA)	▪ Have signed PSA with local utility ▪ Match PSA pricing and escalation to project expenses ▪ Include capacity, energy sales and RECs in energy rate ▪ Negotiate sufficient contract term to match debt repayment schedule ▪ Confirm interconnection point, access and requirements ▪ Include *force majeure* (act of God) provisions in PSA
Energy sales agreements (ESA)	▪ Have signed ESA with energy customer ▪ Set fixed energy sales prices with escalation or market-based prices at sufficient levels to meet financial goals ▪ Obtain customer guarantees to purchase all energy delivered by project ▪ Limit liability for interruptions and have backup energy sources
Financial performance	▪ Create financial *pro forma* ▪ Calculate cash flows and debt coverage ▪ Maintain working capital and reserve accounts ▪ Budget for major equipment overhauls ▪ Avoid hedging on a specific factor – normally outside the control of the project developer – that presents a significant risk to the overall result of the project

Financing Approaches

Several types of approaches can be used to finance a project. The approaches, described below, are not mutually exclusive; a mixture of different approaches may be preferable for a project and might be better suited to meeting specific financial goals. Contact financing consultants, developers, municipal or 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 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 developers, equipment vendors, gas suppliers, industrial companies and investment banks. Private equity financing may be one of the few ways to obtain financing for small projects without access to municipal bonds. Private equity financing has the advantages of lower transaction costs and usually the ability to move ahead faster than with other financing approaches. However, private equity financing can be more expensive and, in addition to a portion of the cash flow, investors might expect to receive benefits from providing funds such as service contracts or equipment sales.

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

Municipal Bond Financing, applicable for municipally owned landfills and municipal end users, involves the local government issuing 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 low (often 1 or 2 percent below commercial debt interest rates) and the terms 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. Project develops should check with the state or municipality where the bond is issued to determine the terms for securing bond financing and the method for qualifying for the bond. Developers also should consider consulting with a tax professional before deciding on whether tax-exempt or taxable bonds should be secured.

Direct Municipal Funding, 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. This approach eliminates the need to obtain outside financing or project partners, and it avoids delays caused from the extensive project evaluations usually required by lenders or partners. However, many municipalities may not have a budget that is sufficient to finance a project, or may have many projects competing for scarce resources. Delays and complications may also arise if public approval is required.

Lease Financing provides a means for the project owner or operator to lease 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 when the term of the lease has been fulfilled. The benefit of lease financing is that it frees up capital funds of the owner or operator while allowing the owner or operator control of the project. The disadvantages include complex accounting and liability issues and loss of tax benefits to the project owner or operator.

Grant Programs offered by many federal and state programs may provide funding for LFG energy projects. A comprehensive and searchable listing of federal and state grant programs is available on the DSIRE website.

Examples

Anne Arundel County's Millersville Landfill Electricity Project, Maryland. After more than 12 years of exploring options and negotiating agreements, Anne Arundel County implemented a 3.2 MW LFG electricity project. The first LFG energy project located in the county, it generates green power for the local grid while providing revenue for county-wide energy efficiency and solid waste projects. A combination of local bond sales and $2 million in American Recovery and Reinvestment Act (ARRA) funding, and cooperation among local, state and federal government contributed to the success of the project.

Orange County's Olinda Alpha Landfill Combined Cycle Project, California. Creative financing was key to implementation of this project that produced the second-largest LFG-fueled power plant (32.5 MW) in the country. Financing included a $10 million ARRA grant from the Department of Energy and a Section 1603 grant from the U.S. Treasury. Positive impacts on the economy stem from local green power usage by the City of Anaheim, annual county LFG revenues of $2.75 million, and manufacture of all major equipment components in the United States.

Landfill owners and operators establish contractual arrangements with end users for the sale of LFG, electricity and other environmental attributes generated by the LFG project. The agreements establish the value of the project and are critical to its long-term success. These agreements are especially essential for projects that rely on financing. Lenders and investors are particularly interested in the structure of contractual agreements and potential risks, which directly affect the terms of the financing. Therefore, landfill owners, operators and project developers should thoroughly evaluate the elements of all potential contractual agreements. This chapter discusses three categories of contracts: power sales agreements (PSAs) (for electricity generation projects), LFG purchase agreements, and environmental attribute agreements. An overview of applicable construction and operating permits is also provided.

> Most LFG energy projects are "must run," meaning that they operate continuously and electricity is not dispatched by a system operator. Operators of dispatchable LFG electricity projects can take advantage of price variations in the electricity market by bringing units online, or taking units offline, in response to demand. Dispatchable LFG electricity projects are typically managed from a central location via remote connection to the facility's supervisory control and data acquisition (SCADA) systems.

5.1 Power Sales Agreements

Traditionally, electricity generated from an LFG energy project has been sold through a PPA to investor-owned utilities (IOUs) that provide electrical service in the region where the project is located. Since the late 1990s, non-regulated entities (such as independent power producers, co-operatives, municipalities, power marketers and power purchasers) have had greater access to the electricity grid, creating competitive electricity markets in many states and regions. With the advent of these competitive markets, electricity providers offer many more options for the purchase of electricity.

Landfill owners and project developers should consider these options carefully. Electricity and other attributes, including capacity, renewable attributes of the power, and ancillary services, can be sold individually or as a "bundled" product. Furthermore, many of these electrical elements can be sold on either a daily basis or for a fixed term.

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 capacity, is sold to the IOU at a fixed price, with some measure of escalation or at an indexed price based on an estimate of short-run avoided cost or publicly available local market price mechanism. Environmental attributes related to the electricity generated by the LFG project may or may not be included in the PPA. Environmental attributes are associated with electricity produced by renewable energy sources and can be referred to as "green power." Executed PPAs can address the transaction of the electricity alone or might include some or all of the green power attributes. 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 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. Electricity generated by an LFG energy project can be sold to power marketers, wholesale buyers or other entities eligible to buy or sell electricity in states and regions with robust electricity markets where electricity pricing is transparent. The contract terms can vary widely; two common terms are:

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

Examples

Examples of states/regions that have robust electricity markets and transparent pricing include:

- PJM Interconnection
- New York Independent System Operator
- California Independent System Operator

Selling Directly Into a Market. Project developers or owners can sell directly into electricity markets for the market price for energy and capacity. The price for energy is usually estimated theoretically a day ahead based on bids received, then updated in real time several times per hour (every 5 to 15 minutes) by the system operator. The market price is set 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 are established for longer time periods — typically 1 to 6 months, but this time 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. As of September 2014, 43 states, Washington D.C., and four U.S. territories offered net metering.[1] Net metering allows consumers to offset their electrical use with appropriately sized renewable electric generation located on site. As a result, the total amount of electricity supplied to the site is reduced, yielding a lower "net" amount of electricity provided by the power company. The operator pays for this "net" amount of power supplied. In some cases, on-site generation may exceed on-site electricity needs. Net metering provisions have emerged to allow operators to sell excess electricity to the local power company and receive credit for the amount of electricity provided back to the electrical grid. The approach allows the LFG energy project to generate and use electricity on-site while maintaining access to grid electricity and creates a source of revenue for the LFG energy project through the sale of excess electricity. States set their own net metering regulations and typically limit the capacity of the generation.

A summary map of net metering policies is available from the DSIRE website.

Other Consideration — Electric Grid Interconnection

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

[1] Database of State Incentives for Renewables and Efficiency (DSIRE). 2014.

- Amount of electricity (MW) the developer wants to connect to the grid
- Size and capacity of surrounding distribution (12 to 15 kilovolt [kV]) and medium tension (20 to 69 kV) distribution lines
- Location of the distribution substation
- Interconnection procedures and regulations
- Utility requirements (such as communications, protection and 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. An interconnect agreement will be required with the utility, as well as agreements for the design and construction of the interconnection.

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 local experience.

5.2 LFG Purchase Agreements

LFG is typically sold for one of three purposes:

1. For use as a substitute for other fuels to create hot air, hot water or steam (for example, to fire boilers, kilns and furnaces). This type is typically referred to as a direct-use project or as a medium-Btu project.
2. To power an LFG-fired electricity generation facility.
3. 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

Direct-use projects use three basic types of contracts: fixed price, indexed price and a fixed/indexed hybrid approach. These contracts are usually set on a Btu-delivered basis. Delivered LFG is commonly sold at a discount to natural gas prices as a result of the following factors:

Indexed pricing bases the cost of LFG on a discount of current natural gas prices.

- Requirements to transport LFG and modify equipment (such as boilers) to use LFG
- Potentially higher O&M costs because LFG has more impurities than natural gas
- Need for the end user to have backup fuels

The level of discount is determined 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 escalates over time 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 the return on investment required by the participating parties. Because of the volatility of natural gas prices, fixed price contracts for LFG are less common.

Indexed Sales Contracts. Indexed sales contracts use natural gas prices to determine the value of the LFG. Normally, the "city gate price" of natural gas is used, which is the price paid by the local natural gas utility and can vary by region. In some cases, price incentives result in discounts to a market price for natural gas. Discounts can vary significantly depending on such factors as local RPS targets, costs of transporting natural gas, the local utility's strategy for incorporating alternative fuels, the amount of investment required for a specific project, and the parties responsible for necessary investments.

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 result in prices that exceed the wholesale indices. Because of the volatility of natural gas prices, indexed LFG sales contracts are highly variable in terms of revenue; however, they can provide the end user with considerable savings.

Natural gas prices have recently been low and indexed sales contracts may not be viable without additional incentives. For example, if biogas is being upgraded to be used as CNG for vehicle fuel, incentives are present to use LFG as a supplement to natural gas. Indexed sales contracts may be more attractive to LFG owners in the future if natural gas prices increase.

To limit price risks on both sides of the contract agreement, indexed contracts typically include provisions for maximum and minimum pricing (e.g., when the government puts a legal limit on how high the price of a product can be [ceiling] and when the government put a legal limit on how low a product can be [floor] prices). 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.

Learn more about floor prices and ceiling prices.

Hybrid Contracts. LFG sales contracts have also been implemented in other creative ways to minimize risk and maximize economic benefits. One such option is a hybrid of the two previous types of contracts. In an example hybrid contract, a fixed price contract is implemented for a certain period of time (for example, 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.

LFG contracts may include a minimum guarantee on the quality and amount of LFG to be delivered and a minimum guarantee on the amount of gas that will be consumed (known as a "take or pay" clause). LFG developers or owners should consider factors such as equipment and potential wellfield uncertainties when they agree to a minimum guarantee on gas delivery. In addition, landfills that are closed or closing in the near future should be cautious about setting aggressive gas quality limits. Conversely, the energy user should consider any routine plant shut-downs or other possible disruptions that would limit the need for gas when setting a minimum consumption guarantee.

LFG Sales to an Electrical Generation Project

These contracts are similar to those developed under a direct-use project application as discussed above. The contractual relationships between the LFG project owner or operator (the electricity generator) and the purchaser of the electricity is provided in greater detail in Section 5.1.

High-Btu Sales

LFG that is purified to natural gas pipeline standards can be injected into a natural gas distribution or transmission line subject to state regulations. When it is sold into a regional distribution line, LFG is typically sold to the distribution company at an indexed price on a Btu basis. When LFG is sold into a natural gas transmission line that transports gas over longer distances before it is distributed, a more complicated contract may be required with the gas transmission line company. Contracts with transmission line companies 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.

To purify LFG to natural gas pipeline standards, the concentrations of carbon dioxide, oxygen, nitrogen and other impurities (such as volatile organic compounds, hazardous air pollutants, hydrogen sulfide and siloxanes) must be reduced. For more information about treating LFG to pipeline standards, see Chapter 3.

5.3 Environmental Attribute Agreements

The LFG energy project developer may sell a project's environmental attributes for additional revenue, or to provide more revenue to the landfill owner. Environmental attributes can be sold together or separately, depending on the market and the nature of the contract entered into by the landfill owner or LFG energy project owner. Broadly, there are two types of environmental attributes:

- Direct – destruction of methane (a potent GHG)
- Indirect – displacement of fossil fuel use by LFG use, a renewable energy resource

All contracting parties should ensure that ownership of the environmental attributes, including the rights to the GHG emission reductions, are clearly defined. Historically, agreements have been relatively clear about ownership of LFG rights; however, contract language has not been as clear with respect to evolving environmental markets and incentives such as renewable energy certificates, tax credits and GHG credits. A clear definition of which party owns each of the environmental attributes of the LFG is critical for new project agreements and amendments to older agreements.

For information about renewable energy tax credits or other incentives to improve project financial feasibility, see Chapter 4.

GHG Credits Derived from the Destruction of Methane in LFG

The GHG 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 GHG emissions can indirectly fund LFG collection and control projects through the purchase of GHG emission reduction credits from landfills. These GHG credits are traded in units of metric tons of carbon dioxide equivalent. Currently, GHG credits are traded in either a compliance or voluntary market; no single market, nor single standard for the trade of GHG credit currently exists.

For a landfill's project to qualify for a GHG 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 NSPS. Generally, a project does not qualify for GHG credits if the landfill is required to collect and control LFG under any local, state or federal regulations for control of emissions, odors 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 GHG transactions currently take place in a voluntary market, which is composed of sellers, buyers, brokers and aggregators who are voluntarily trading GHG credits with the goal of reducing the buyer's carbon footprint. Voluntary market transactions occur in several over-the-counter (OTC) markets.[2]

Participants in voluntary OTC markets, or firms investing in GHG credit projects, will sign agreements with landfill owners to obtain the right to the GHG 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 GHG credits. Contract structures may provide ongoing revenue sharing or may allow the equity provider to recover their investment before revenue is shared with the landfill. This structure would apply for agreements where the GHG investment firm provides equity for all or part of a gas collection and control system. GHG agreements where equity is provided are typically longer-term agreements (up to 10 years) to minimize capital recovery risk by the investor. Simple GHG credit purchase agreements where significant equity is not provided can have a much wider range in the length of the agreement. These non-equity GHG purchase agreements may address the transaction of a discrete amount of previously generated GHG credits, or may provide a longer-term (or forward) agreement for the rights to future GHG credit generation.

Voluntary GHG markets are established when an entity (or group) takes the initiative to offer one in light of a perceived unmet level of interest among potential buyers and sellers of GHG credits. The continued existence of a given voluntary market is a reflection of adequate levels of seller and buyer participation. These voluntary markets are typically independent of each other, and no one standardized methodology or protocol exists among these markets for determining eligibility of credits. These voluntary markets operate using several different standards and protocols for determining project eligibility and verifying the GHG credits. Carbon standards include the Verified Carbon Standard, the Gold Standard, the California Climate Action Registry and the American Carbon Registry. Protocols outline project eligibility, monitoring, recordkeeping, quantification, and reporting requirements. GHG methodologies applicable to landfill projects in the voluntary markets currently include:

A *standard* is the overall framework of a GHG program, whereas a *protocol* is a specific set of requirements that outline how GHG credits are developed for a specific project, such as an LFG energy project.

- Climate Action Reserve Landfill Project Protocol Version 4.0
- California Climate Registry
- Greenhouse Gas Protocol
- EPA Center for Corporate Climate Leadership

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 calculate this conversion, the amount of methane destroyed is multiplied by the global warming potential of methane, which can range from 21 to 28 depending on which GHG standard or protocol is used. Once a third party

2 Maneuvering the Mosaic: State of the Voluntary Carbon Markets 2013. Forest Trends' Ecosystem Marketplace and Bloomberg New Energy Finance. June 20, 2013. http://www.forest-trends.org/vcm2013.php.

has verified the GHG credits, they may become verified emission reductions, carbon financial instruments, or other protocol-defined instruments, depending on the market or the protocol used by the buyer.

> The GHG credits generated by the voluntary 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 are 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 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 GHG offsets to this market.

California enacted a bill (AB-32) in 2006 that required the Air Resources Board (ARB) to establish rules to reduce GHG emissions. The ARB implemented an enforceable cap-and-trade program in 2012.[3] The Western Climate Initiative — including California and Canadian provinces — is working to develop a regional GHG reduction program, including a cap-and-trade system. As these and other mandatory programs are developed, they might create additional opportunity for revenue streams from LFG projects, depending on whether the final rules allow landfills to provide GHG offsets.

Renewable Energy Attributes of LFG Energy Projects

LFG energy project developers and 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 fossil fuel use to create energy when LFG energy projects are implemented.

RECs. Many states have or are adopting RPS. A state RPS requires an electrical supplier, provider or distributor who sells to retail customers (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. RECs are the tradable units that allow electric services providers to meet RPS requirements; a typical REC represents the environmental attributes of 1 MWh 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, more commonly 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 the value of the REC. Many utilities have already met their obligations for the upcoming years and may not be interested in buying more RECs. It is therefore

> DSIRE™ Database of State Incentives for Renewables & Efficiency
>
> Up-to-date information about RPSs is available from the Database of State Incentives for Renewables and Efficiency (DSIRE) website.

[3] California Environmental Protection Agency, Air Resources Board, Cap-and-Trade Program. http://www.arb.ca.gov/cc/capandtrade/capandtrade.htm.

important that project developers contact all potential buyers to make sure the project being considered can generate sufficient revenues to be financially viable.

U.S. EPA Green Power Partnership

The Green Power Partnership is a voluntary program that encourages organizations to buy green power as a way to reduce the environmental impacts associated with purchased electricity use. The partnership currently has more than 1,300 partner organizations voluntarily purchasing billions of kilowatt-hours of green power annually.

***GHG Displacement Credits*.** An LFG energy project can generate GHG 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 GHG 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 GHG emissions reduction credits for the destruction of the LFG if their PSAs allow for these sales. Additionally, some programs provide GHG credits for 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 Construction and Operating Permits

Landfills and LFG energy projects are subject to federal, state and local air quality, solid waste, and water quality regulations and permitting requirements. Specific construction and operating permit requirements may differ among states. Project developers will need to contact relevant federal, state and local agencies for more detailed, current information and to obtain permit applications for various types of construction and operating permits. The following provides general information about permitting requirements. Project developers are responsible for ensuring compliance with applicable regulations.

An overview of the regulatory framework is provided in Chapter 1. Further information for selected states is available on LMOP's State Resources page.

Permitting Requirements Under the Clean Air Act (CAA)

The CAA regulates emissions of pollutants to protect the environment and public health and contains provisions for NSR permits and Title V permits.

Overview of NSR Permitting. New LFG energy projects may be required to obtain construction permits under the NSR. Depending on the area where 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 will depend on the level of emissions resulting from the technology used and the project's location (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 where they are located. Because these regulations are complex, a landfill owner or 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.” Specific permit requirements will vary by state 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. (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 assess PSD applicability for each individual pollutant. The PSD major NSR permitting process requires that the applicants determine the maximum degree of reduction achievable through the application of available control technologies for each pollutant for which the source is considered major. Specifically, major sources may have to undergo any or all of the following four PSD steps:

- Best available control technology analysis
- Monitoring of local air quality
- Source impact analysis and modeling
- Additional impact analysis/modeling (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. State agencies should be contacted 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 these 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 (in other words, if the new or modified source exceeds specified emissions thresholds). A project must meet two requirements to obtain a nonattainment major NSR permit for criteria pollutants:

- Must use technology that achieves the lowest achievable emissions rate 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 nonattainment NSR that have been determined to apply to the individual LFG energy project. A Title V operating permit must be renewed every 5 years.

PSD and Title V GHG Tailoring Rule. This rule, promulgated on May 13, 2010, set thresholds for GHG emissions that define when CAA permits under Title V and NSR permit programs would be required for new or existing industrial facilities. The thresholds for criteria pollutants are 100 or 250 tons per year, which are appropriate for criteria pollutants but are not feasible for GHGs. The GHGs covered by this rule include carbon dioxide, methane and nitrous oxide. The rule does not include an exemption for biogenic carbon dioxide.

Information about how EPA is phasing in the CAA permitting requirements for GHGs are available on EPA's Clean Air Act Permitting for Greenhouse Gases website. More information about the PSD and Title V GHG Tailoring rule is available on EPA's New Source Review website.

Resource Conservation and Recovery Act (RCRA) Subtitle D

Before an LFG energy project can be developed, all RCRA Subtitle D requirements (requirements for nonhazardous solid waste management) must be satisfied. In particular, methane is explosive in certain concentrations and poses a hazard if it migrates beyond the landfill 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 (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 condensate forms when water and other vapors condense out of the gas stream because of changes in temperature and pressure 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. LFG energy projects may need to obtain NPDES permits if wastewater is discharged directly to a receiving water body. These energy projects are categorized as direct sources. 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 5 years, limit the quantity and concentration of pollutants that may be discharged. Permits require wastewater treatment or impose other operating conditions to ensure compliance with the limits. 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

LFG energy projects that discharge wastewater to a POTW instead of directly into a water body are categorized as indirect sources and are regulated under the National Pretreatment Program, a subcomponent of the NPDES Permit Program. Under this program, industrial users are required to obtain permits that may specify effluent discharge limits that must be met before wastewater can be conveyed to the POTW. In some cases, pretreatment of the wastewater may be required to meet effluent discharge limits.

Clean Water Act (CWA) Section 401 Certification

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 these pipes causes any discharge of dredged material into streams or wetlands, the project may require CWA Section 401 certification. The applicant must obtain a water quality certification from the state where the discharge will originate. The certification should then be sent to the U.S. Army Corps of Engineers. The certification indicates that the 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 concentrations of heavy metals and organic chemicals high enough for it to be classified as a hazardous waste, thus triggering federal Subtitle C regulation.
- Projects that transport LFG via pipeline are subject to 49 CFR Part 192 – *Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards* if the LFG pipeline crosses or impedes public property. The Department of Transportation's OPS is the main regulatory agency responsible for regulating the operation and maintenance of jurisdictional natural gas pipelines. Many state agencies have adopted the regulations and can regulate jurisdictional pipelines within their states.
- 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.

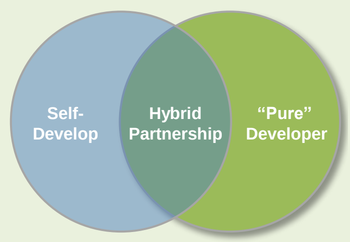
6. Evaluating and Working with Project Partners

Successful LFG energy projects involve the contributions of landfill owners, project developers, energy end users and project partners. This chapter outlines how landfill owners can find and evaluate project partners and discusses the roles of each partner during project development. This discussion covers projects that are “self-developed” by the landfill owner and “pure developer” projects that use an outside energy project developer. The chapter also discusses LFG energy project partnering from an end user’s perspective, focusing on considerations and evaluation techniques that end users may wish to consider before selecting partners and entering into agreements.

6.1 Approaches to Project Development

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

- **Use an Outside (“Pure”) Project Developer:** An outside project developer can finance, construct, own or operate the LFG energy project.
- **Self-Develop:** A landfill owner or 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.



Hybrid approaches to developing an LFG energy project involve shared responsibilities among the landfill owner/operator and outside developers. Hybrid approaches draw on the same principles presented in this chapter.

As shown in Figure 6-1 on the next page, there are several key questions that should be considered when making the determination to self-develop or to secure an outside “pure” project developer. Before the decision is made, landfill owners should carefully assess their willingness and expertise to undertake each of the steps to self-develop an LFG energy project and evaluate their tolerance for risk.

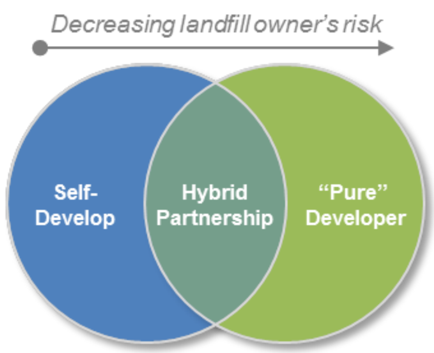
In all cases, the landfill owner, energy end user and LFG energy project owner will need assistance from outside partners, which typically include consulting engineers, lawyers, contractors, regulatory and planning agencies, community members and financial professionals. The involvement of multiple partners helps to ensure timely development of an LFG energy project that is financially feasible and benefits the environment and the local community.

ⓘ For a full list of LMOP Partners, see the [LMOP website](). Details about the various categories of partners are provided, including lists of partners available to assist different segments of the LFG community.

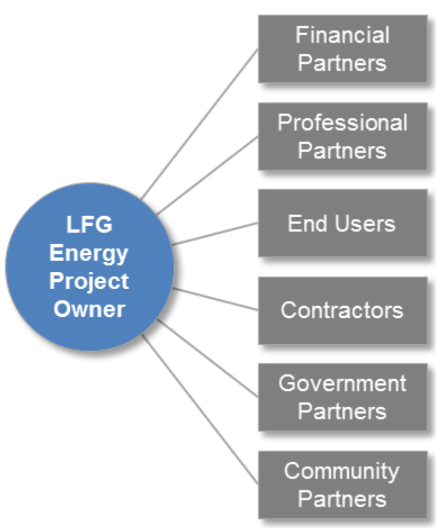
Figure 6-1. Considerations for Selecting the Project Development Approach

Key questions to be considered when determining whether to self-develop or secure an outside "pure" developer:

- Is there a desire for the landfill owner to self-develop?
- Does the landfill owner have the expertise necessary to self-develop?
- Is it economically viable for the landfill owner to self-develop?
- How much risk is the landfill owner willing to accept?



Project owners interact with several types of partners to obtain expertise and services necessary to make the LFG energy project successful.



Overview of Steps to Self-Developing an LFG Energy Project

Determine LFG supply (calculations, computer modeling, test wells)

Scope the project (location selection, sizing energy output to LFG supply, contacting energy customers, technology and equipment identification)

Conduct feasibility analysis (detailed technical and economic assessments, estimation of project revenues and other measures of economic performance)

Design the plant, pipeline or project

Select equipment based on the results of the feasibility analysis (selection of primary equipment, contacting vendors, assessment of price, performance, schedule and guarantees)

Create a financial *pro forma* (updates to feasibility analysis using information submitted in actual bids from vendors)

Negotiate the power sales or gas sales agreement (negotiation of terms of the agreements with purchasing utilities or end users)

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 agreements (negotiation of ownership agreements with partners or investors)

Secure financing (attainment of expertise based on financing approach 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. An economic feasibility study is prepared to determine whether the landfill owner has enough capital available. Results of this study are evaluated for capital needs, IRR and other financial needs. The landfill owner considers available capital and financing options (such as private financing or municipal bonds) to determine whether sufficient funding is available or can be obtained. If the landfill chooses to hire a developer, the developer would obtain the funding.

For more information about economic feasibility studies and financing, see Chapter 4.

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. A qualified project manager 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 2 years). If a landfill owner does not have a project manager on staff, then he or she should consider contracting for an outside project manager 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 operate 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, 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 are shown in Table 6-1.

Table 6-1. Types of Risks for LFG Energy Projects

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

Advantages of the Pure Developer or Hybrid Approach. 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 on line faster.
- The developer may have numerous other LFG energy projects, which may reduce capital and O&M costs through economies of scale.
- The developer may invest equity or have access to financing.
- The developer might possess a PSA that was previously 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 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 because the developer retains responsibility of construction, development and performance risk and the landfill owner assumes the financial performance risk.

Advantages of the Self-Development Approach. There are advantages to self-developing a project in spite of the increased risks to the landfill owner. For example, the landfill retains control and holds a larger share of the profits. In addition, developing a project may be a rewarding challenge and opportunity for landfill staff, and these projects can foster good relationships with end users, other partners and the community.

Examples

Brown Station Road On-Site Electrical Generation Project, Maryland. Since 1987, Brown Station Road Landfill has been sending LFG to the nearby Prince George's County Correctional Facility to generate steam and electricity. In 2003, the county completed its gas expansion project and installed four new engines. Today, the county sells green power to the local utility for sale on the grid. The project provides $60,000 per month in revenue to the county; annual energy savings equate to powering 1,800 homes.

Wayne Township Landfill Gas Energy Project for Jersey Shore Steel, Pennsylvania. Approximately 12 million Btus of heat an hour were being flared. The General Manager of the landfill realized the landfill was approved to accept waste through 2016 and considered how to raise revenues and support the community from the flaring. The project preserved 250 local jobs and saves 30 percent of natural gas costs (more than $900,000 annually).

The "pure" 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 Selecting a Project Developer (Pure Development Approach)

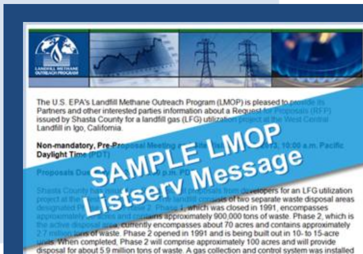
Finding Qualified LFG Energy Project Developers

Landfill owners who decide to employ a developer should investigate 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. Typically, project developers and other partners provide a Statement of Qualifications (SOQ), which is a document that describes the experience, staff qualifications and other important factors that may influence the landfill owner's final decision.

Another method of evaluating developers for a landfill owner is issuing an RFP. Although private landfill owners do not normally issue RFPs to developers, RFPs provide a competitive and fair basis of evaluation. All of the landfill owner's requirements should be identified in the RFP, as well as information about the LFG resource. Landfill owners sometimes hire consultants to help them develop and evaluate responses to an RFP. LMOP can provide landfill owners with example RFPs and can help distribute RFPs via LMOP's email listserv.



LMOP can help distribute RFPs via LMOP's listserv.

Evaluating Developers

After the landfill owner receives proposals from various developers, the next step is to evaluate the proposals, sometimes with the assistance of a consultant. In reviewing the proposals, landfill owners typically compare SOQs, proposals or RFP responses to evaluate the developer's expertise, technical approach, financial advantages to the landfill owner, business experience and schedule for implementation. After the proposals have been evaluated, the landfill owner selects the developer who adds the most value and begins negotiations. Various methods are available to evaluate proposals, ranging from a checklist to a ranking matrix that lists the evaluation criteria with a scoring system.

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

Ranking Matrix. A ranking matrix would be a better tool for completing the evaluations for a landfill owner who considers RFP requirements to vary in importance. For example, if a landfill owner has been unsuccessful in developing an LFG energy project at their facility, making sure that the developer's approach is technically sound might be the most important factor in selecting a developer. However, the royalty paid by the developer might be the more important requirement for another landfill owner who considers an addition to the landfill's net income to be most important. Table 6-2 presents potential evaluation criteria that landfill owners might use to evaluate an LFG energy project developer.

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

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

MMBtu: Million British thermal units   O&M: operations and maintenance

6.3 Identifying Project Partners (Self-Development Approach)

Landfill owners who decide to self-develop typically partner with persons or institutions that provide assistance during the development and operation stages of the LFG energy project. These partners typically include financial partners, such as bankers and accountants; professional consultants, such as consulting engineers and lawyers; and contactors, such as equipment manufacturers and construction contractors. Under this approach, the landfill owner manages, owns and operates the LFG energy project.

The process for contracting with a partner under the self-development approach is the same as contracting with a developer for the pure developer approach. Landfill owners often issue RFPs to prospective partners. Each RFP is tailored to the type of partners and role to be performed 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 are typically customized depending on the type of partner and the specific statement of work in the RFP, but general criteria include:

- Project cost
- Project experience
- Staff qualifications
- Project approach
- Risk management
- Time frame to implement

Finally, the landfill owner uses the same methods described in "Evaluating Developers" (in Section 6.2) to review proposals and award projects to prospective partners.

6.4 Interacting with Project Partners

LFG energy project owners 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
- Professional
- End users
- Contractors
- Government
- Community

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 and accountants. Table 6-3 describes how each one of these partners is involved in the LFG energy project.

Table 6-3. Financial Partners for LFG Energy Projects

Partner	Purpose
Tax creditor	Assists LFG energy project owners in identifying and applying for available federal, state and local 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 financial 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 whether 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 6-4. 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 owners who use a developer will still need to interact with the professionals listed in Table 6-4. 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. Landfill owners 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 are provided to the project and that applicable air regulatory requirements are met.

Table 6-4. 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 (for example, 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, and 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 project. ▪ Prepare educational materials about the project.

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 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, 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 (for example, the LFG quantity, LFG energy content, pressure and temperature) or electricity requirements, so that the LFG energy project owner can design and operate the 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 should continue after the project becomes operational to ensure the success of the project. 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 6-5 describes the responsibilities of contractors.

Table 6-5. 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 which is provided by the manufacturer.
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 the 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 a contract, construction activities and initial project performance evaluation (the time when 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 operators	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. After 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 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 owner’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 will be 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 is not operating, since this circumstance usually requires the landfill owner to use a different method to control LFG emissions (with a backup flare).

Government 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 partners, including regulatory and planning agencies.

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 applications are prepared 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
- State or local air quality agencies or departments
- County board members
- Local solid waste planning boards
- Local economic development agencies
- Local zoning and planning departments

These partners are involved primarily during the process of siting and permitting the facility. Discussions between the LFG energy project owner and the 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 websites:

- LMOP State Resources page
- Database of State Incentives for Renewables and Energy

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, members of the 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 to help the LFG energy project owner understand and address any community concerns.

Unless there is significant opposition to the LFG energy project, community partners are mainly involved during the permitting process. LFG energy project designs should adhere to all local ordinances and zoning, and the anticipated environmental and economic benefits to the surrounding community should be clearly identified and communicated. When LFG energy project owners apply for the required permits (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 (or support for) 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 the planning of an LFG energy project can help ensure that the type of LFG energy project chosen is a good fit for the community and provides environmental and economic benefits to the community.

6.5 Evaluating Projects from an End User's Perspective

LFG energy end users who make contractual agreements with LFG project owners or project developers also have issues to consider before they enter into negotiations. End users should perform due diligence on the prospective LFG energy project owner and evaluate several aspects of the proposed project, including technical, financial and regulatory implications. End users may conduct their own research or obtain professional services from consultants who specialize in performing due diligence. In either case, end users typically consider the following issues:

- 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 (such as boilers, internal combustion engines and gas turbines)
- Landfill owner and developer financial assurances
- Contractual terms

Evaluating and Negotiating with Landfill Owners and Developers. Evaluation begins with comparing the results of due diligence studies with the end user's requirements (financial goals, business objectives and project schedule). If the proposed project meets the end user's requirements, 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. Before entering into any contracts with project partners, end users should assess potential partners by examining their past experience with LFG energy projects, their project approaches, financial proposals and schedules. By working closely together throughout the project development process, end users and their partners will help to ensure that the LFG energy project produces environmental and economic benefits for the end user, the landfill owner and the community.

www.epa.gov/lmop/publications-tools/handbook.html