

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 (GHGs) 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

LMOP 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?

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 (NMOCs) and trace amounts of inorganic compounds. Methane is a potent GHG 28 to 36 times more effective than carbon dioxide at trapping heat in the atmosphere over a 100-year period.¹ LMOP uses a methane global warming potential (GWP) of 25 in program calculations to be consistent with and comparable to key Agency emission quantification programs such as the U.S. GHG Inventory.²

MSW 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 2014.²

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.

¹ In the latest Intergovernmental Panel on Climate Change (IPCC) assessment report (AR5), the methane GWP range is 28 to 36, compared to a GWP of 25 in AR4. <https://www.ipcc.ch/report/ar5/>.

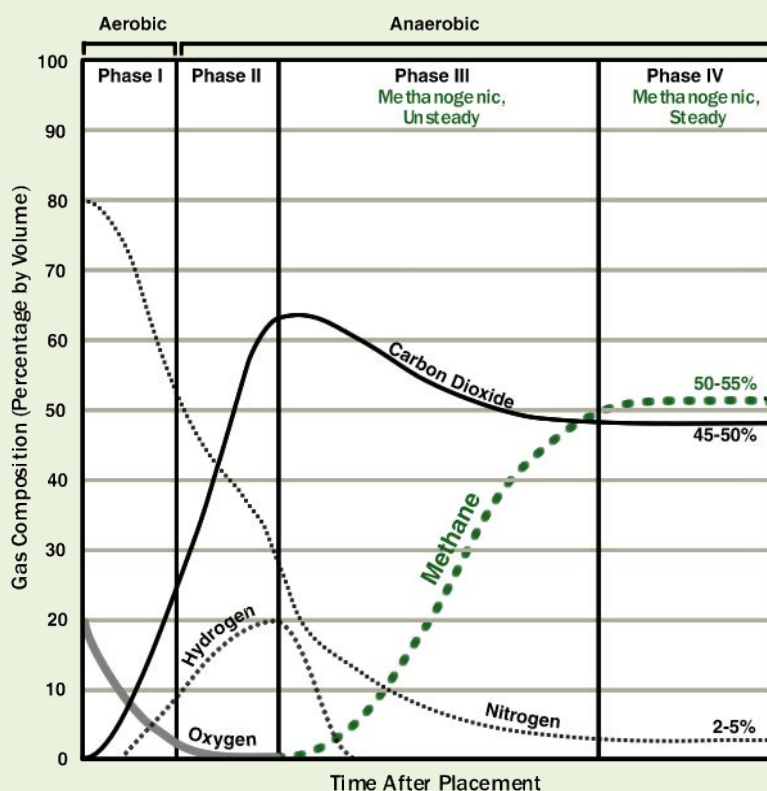
² *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014*. U.S. Environmental Protection Agency. EPA 430-R-16-002. April 2016. <https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990-2014>.



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 EPA's [Facility Level Information on GreenHouse gases Tool \(FLIGHT\)](#).

Figure 1-1. Changes in Typical LFG Composition after Waste Placement³

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 254 million tons of MSW were generated in the United States in 2013, with less than 53 percent of that deposited in landfills.⁴ One million tons of MSW produces roughly 300 cubic feet per minute (cfm) 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](#).

³ 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

⁴ Of the MSW generated in 2013, more than 34 percent was recovered through recycling or composting while about 13 percent was combusted with energy recovery. Source: U.S. EPA. 2015. *Advancing Sustainable Materials Management: 2013 Fact Sheet*. EPA-530-R-15-003. Figure 4, p. 5. https://www.epa.gov/sites/production/files/2015-09/documents/2013_advncng_smm_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

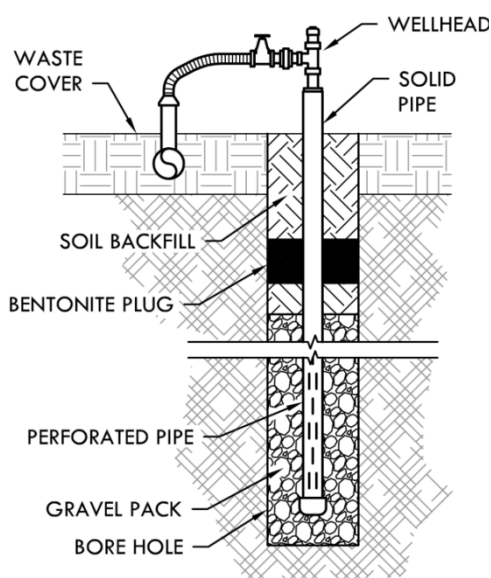
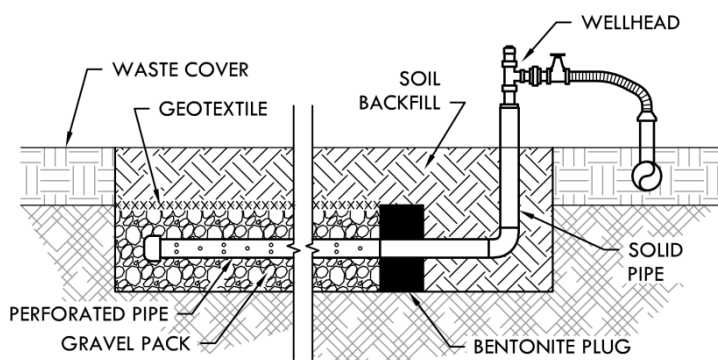


Figure 1-3. Horizontal Extraction Well



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.⁵ 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

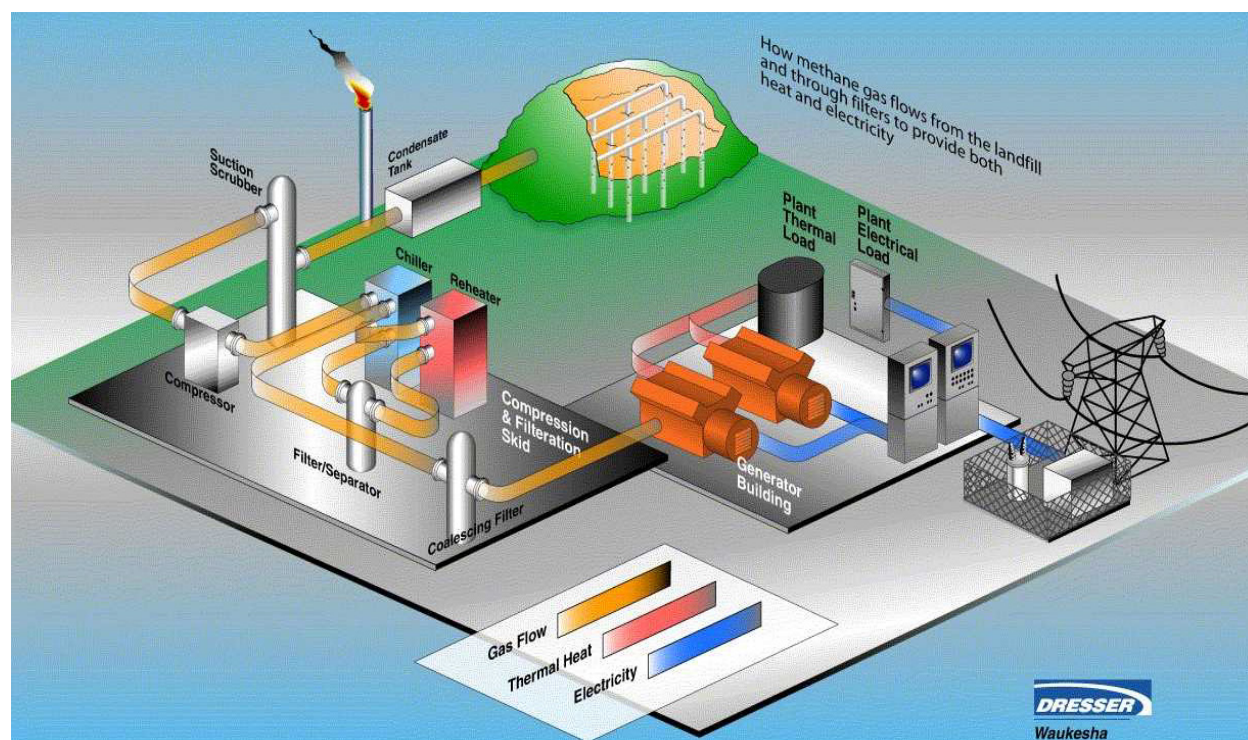
Using LFG in an energy recovery system usually requires some treatment of the LFG to remove excess moisture, particulates and other impurities. The type and extent of treatment depend on site-specific LFG characteristics and the type of energy recovery system employed. Boilers and most internal combustion 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.⁶

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.

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

⁶ 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

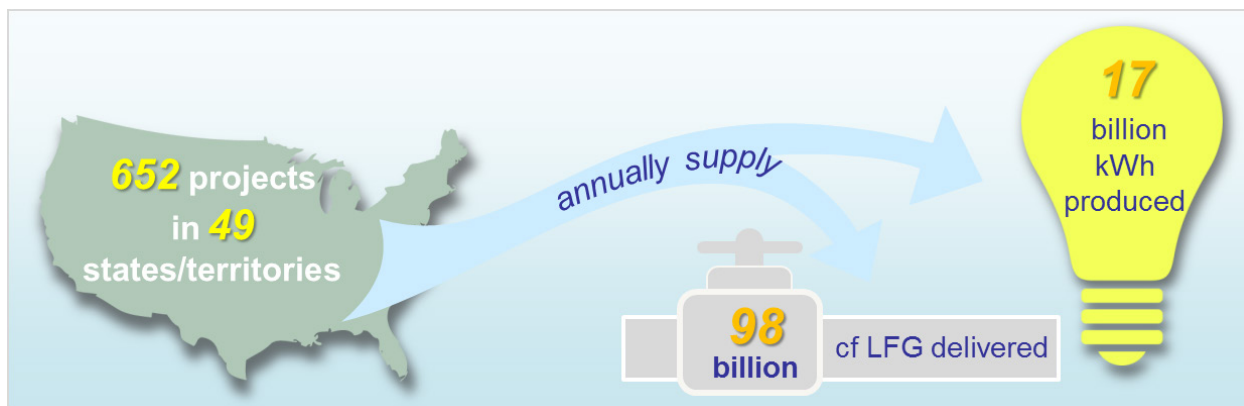
LFG energy projects first came on the scene in the mid- to late-1970s and increased notably during the 1990s as a track record for efficiency, dependability and cost savings was demonstrated. The enactment of federal tax credits and regulatory requirements for LFG collection and control for larger landfills 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 300 cubic feet per minute of LFG. Through various technologies, this amount of 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, in 2016, 652 LFG energy projects are operating in 48 states and 1 U.S. territory. Roughly three-quarters of these projects generate electricity, while the remainder are either direct-use projects where the LFG is used for its thermal capacity or upgraded LFG projects where the LFG is cleaned to a level similar to natural gas. 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 652 projects are estimated to generate 17 billion kilowatt-hours (kWh) of electricity and deliver 98 billion cubic feet of LFG to direct end users and natural gas pipelines annually.⁷ More information about these projects as well as landfills with potential to support LFG energy projects is available on the [Landfill Gas Energy Project Data and Landfill Technical Data page](#) of LMOP's website.

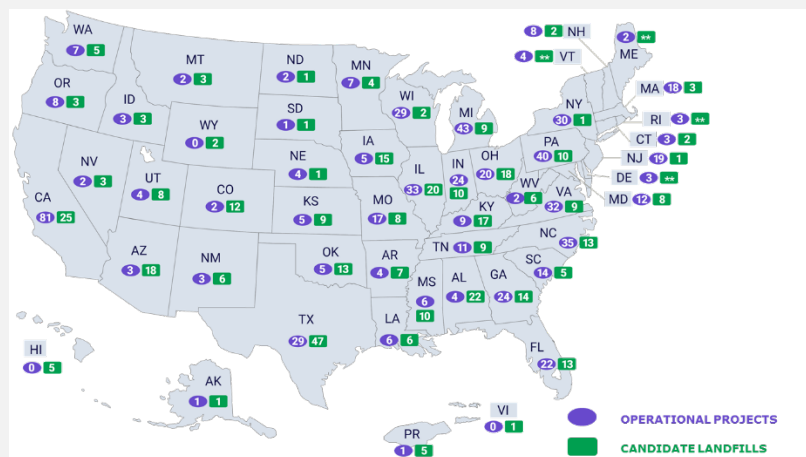
Figure 1-6. Estimated LFG Energy Project Output in the United States (July 2016)



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 files](#) of operational projects and candidate landfills on its website.

Each file includes basic information about the landfill or project, such as location, data on LFG flow rates, project status and technology type.



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 75 percent) of the LFG energy projects that generate electricity use internal combustion engines, which are well-suited for 800-kW to 3-megawatt (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

⁷ U.S. EPA. LMOP Landfill and LFG Energy Project Database. July 2016.

projects smaller than 1 MW. Small internal combustion engines are also available for projects in this size range.

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.

Other 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. LFG has also found a home in a few greenhouse operations.
- **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.



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.⁸ Methane is a potent heat-trapping gas (25 times stronger than carbon dioxide over a 100-year period) and has a short atmospheric life (~12 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.⁹

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.¹⁰

GHG Equivalents¹¹

The 652¹² LFG energy projects operational in 2016 reduce approximately 135 million metric tons of carbon dioxide equivalents (MMTCO_{2e})/year of GHG emissions, which is equivalent to any one of the following:

Carbon sequestered by nearly 103 million acres of U.S. forests in one year

or

Carbon dioxide emissions from more than 312 million barrels of oil consumed

or

Carbon dioxide emissions from about 15.2 billion gallons of gasoline consumed

⁸ *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014*. U.S. Environmental Protection Agency. EPA 430-R-16-002. April 2016. <https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990-2014>.

⁹ 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/>.

¹⁰ 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.

¹¹ U.S. EPA. Greenhouse Gas Equivalencies Calculator. <https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator>.

¹² U.S. EPA. LMOP Landfill and LFG Energy Project Database. July 2016.

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:

- NMOCs 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.



LMOP's [LFG Energy Benefits Calculator](#) estimates 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 LFG electricity 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 annual GHG emission reductions are equivalent to the carbon dioxide emissions from nearly 342,000 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 System. 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 was 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's manufacturing plant](#) in Greer, South Carolina. The project saves BMW approximately \$5 million annually in energy costs.

LFG Electricity and Heat at Morgan County Regional Landfill in Alabama. Winner of the LMOP 2011 Community Partner of the Year Award, 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 online in 2010, and the city brought a second engine online 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 a nearby privately owned 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 then landfill owner Fred Weber, the direct-use project was brought to fruition and the school began saving about \$27,000 per year.

Revenue Creation ¹³			
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 project economics, financing or funding resources, see [Chapter 4](#).
For more information about options when setting up a contract, see [Chapter 5](#).

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.



Links to state agencies are available on LMOP's [State Agencies page](#).

MSW landfills are required to report GHG emissions and other data if their annual CH₄ 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 June 28, 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

¹³ U.S. EPA LMOP. *LFGcost-Web*, Version 2.2.

combustion engines. Rule and implementation information for NSPS for internal combustion engines is available on EPA's Air Toxics webpage for [stationary internal combustion engines](#).

NSPS and EG for MSW Landfills. On August 29, 2016, EPA published final updates to its NSPS for new, modified and reconstructed MSW landfills and also issued guidelines for existing MSW landfills. Both actions require affected landfills to install and operate a gas collection and control system after LFG emissions reach a threshold of 34 megagrams (Mg) of NMOCs per year. Landfill owner/operators may control gas by combusting it in an enclosed combustion device (such as a boiler, engine or turbine) for energy generation, by using a treatment system that processes the collected gas for sale or beneficial use, or by flaring it. Information on the NSPS and EG can be found online on EPA's Air Toxics webpage for [MSW landfills](#).

NESHAP for MSW Landfills. LFG energy projects can be part of a compliance strategy to meet EPA's [landfill NESHAP](#). Under this January 16, 2003 rule, landfills meeting certain design capacity, age and emissions criteria are required to collect and control LFG. Subject landfills that operate part or all of the landfill as a bioreactor must install collection and control systems for the bioreactor earlier than would otherwise be required by the NSPS. 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 require semi-annual compliance reporting, instead of the annual reporting required by the NSPS.

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.

EPA promulgated additional amendments to this NESHAP on January 30, 2013 related to alternative testing options for certain engines, management practices for certain engines, and other topics. 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.

On November 20, 2015, EPA finalized revisions to the 2013 amendments as a result of reconsideration of three provisions. The final rule and earlier rules are available on [EPA's Air Quality Planning and Standards 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 offsite 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 onsite 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 or 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 LFG generation potential.

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 emission 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. See [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 Agencies 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. General information about federal, state and local financing programs and incentives is available on LMOP's [Resources for Funding LFG Energy Projects 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.