1. Landfill Gas Energy Basics

Harnessing the power of landfill gas (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, it introduces general steps to LFG energy project development.

1.1 What Is LFG?

MSW landfills are the third largest human-caused source of methane in the United States, accounting for approximately 15.1 percent of U.S. methane emissions in 2019.[2]

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] The Landfill Methane Outreach Program (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] 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.

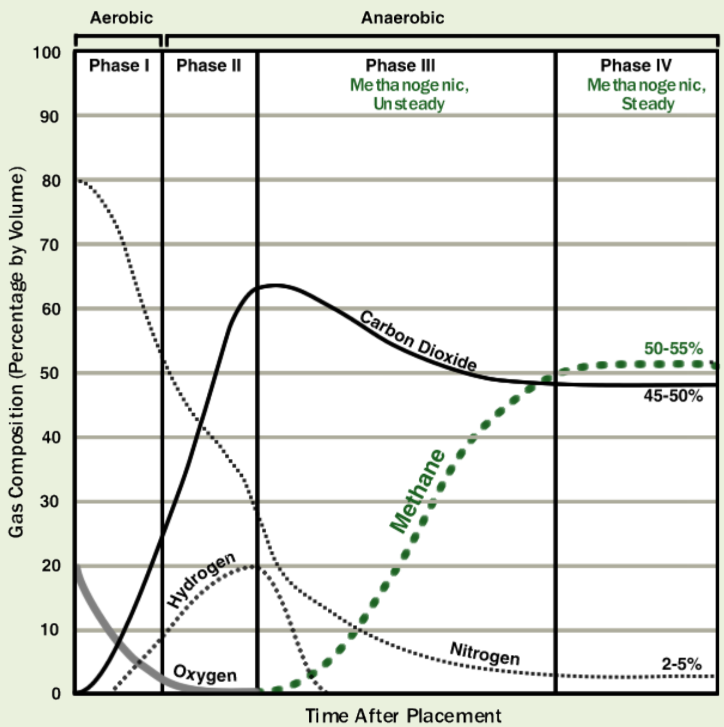
1 In the latest Intergovernmental Panel on Climate Change (IPCC) assessment report (AR5), the methane GWP range is 28 to 36, compared to a GWP of 25 in AR4. https://www.ipcc.ch/report/ar5/.

2 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019*. U.S. Environmental Protection Agency. EPA 430-R-21-005. April 2021. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019.

More information about national GHG emissions from landfills and other sources is available from EPA's national [Greenhouse Gas Emissions](#) 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 Placement[3]

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 292 million tons of MSW were generated in the United States in 2018, with about 50 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 (Btus) 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. https://www.atsdr.cdc.gov/HAC/landfill/PDFs/Landfill_2001_ch2mod.pdf.

[4] Of the MSW generated in 2018, more than 38 percent was recovered through recycling or composting while about 12 percent was combusted with energy recovery. Source: U.S. EPA. December 2020. *Advancing Sustainable Materials Management: 2018 Fact Sheet*. https://www.epa.gov/sites/production/files/2021-01/documents/2018_ff_fact_sheet_dec_2020_fnl_508.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. A gas collection system (GCS) can be configured with vertical wells, horizontal trenches or both, and its design can vary based on factors such as location, operational goals and waste filling practices. 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 GCS 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 GCS uses horizontal piping laid in trenches in the waste. Horizontal trench systems are useful in deeper landfills and in areas of active filling. Some 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 the GCS 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

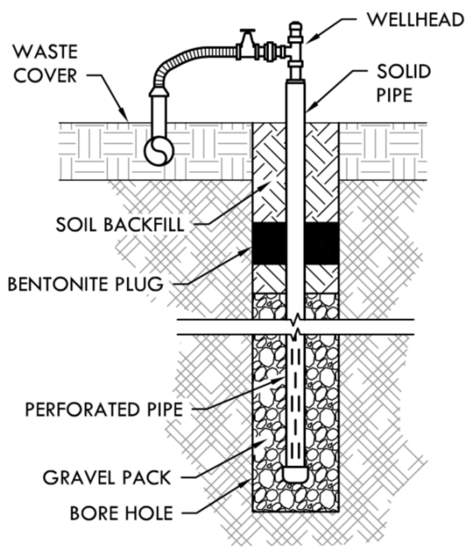
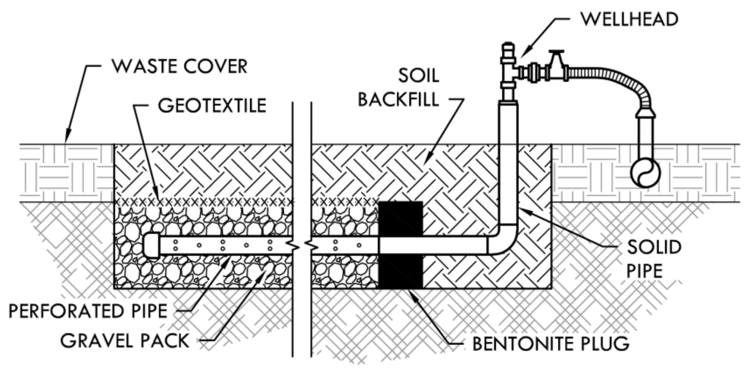


Figure 1-3. Horizontal Extraction Well



Condensate Collection. Condensate (water) forms when warm gas from the landfill cools as it travels through the GCS. If condensate is not removed, it can block the piping and disrupt the LFG 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 GCS 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 Gas Collection and Control System (GCCS) Costs

Total GCCS costs vary widely, based on a number of site-specific factors. For example, if the landfill is deep, costs tend to be higher because well depths will need to be increased. Costs increase with the number of wells installed, and costs will vary based on the type of flare used.

The estimated capital required for a 40-acre GCCS (including a utility flare) designed for 600 cfm of LFG is approximately $1,313,000, or $32,800 per acre (2020 dollars), assuming one well is installed per acre. Typical annual operation and maintenance (O&M) costs for this GCCS are estimated to be $221,000, or $5,500 per acre.[5] If an LFG energy project generates electricity, often a landfill will use a portion of the electricity generated to operate the GCCS and sell the rest to the grid to offset these operational costs. Flaring costs are incorporated into these estimated capital and O&M costs, because excess gas may need to be flared at any time even if an energy generation system is installed.

For more information about GCS design and installation, see Chapter 7. For more information about GCS O&M, see Chapter 8.

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 (H_2S) removal using adsorption beds, biological scrubbers and other available technologies after the dehumidification step.[6]

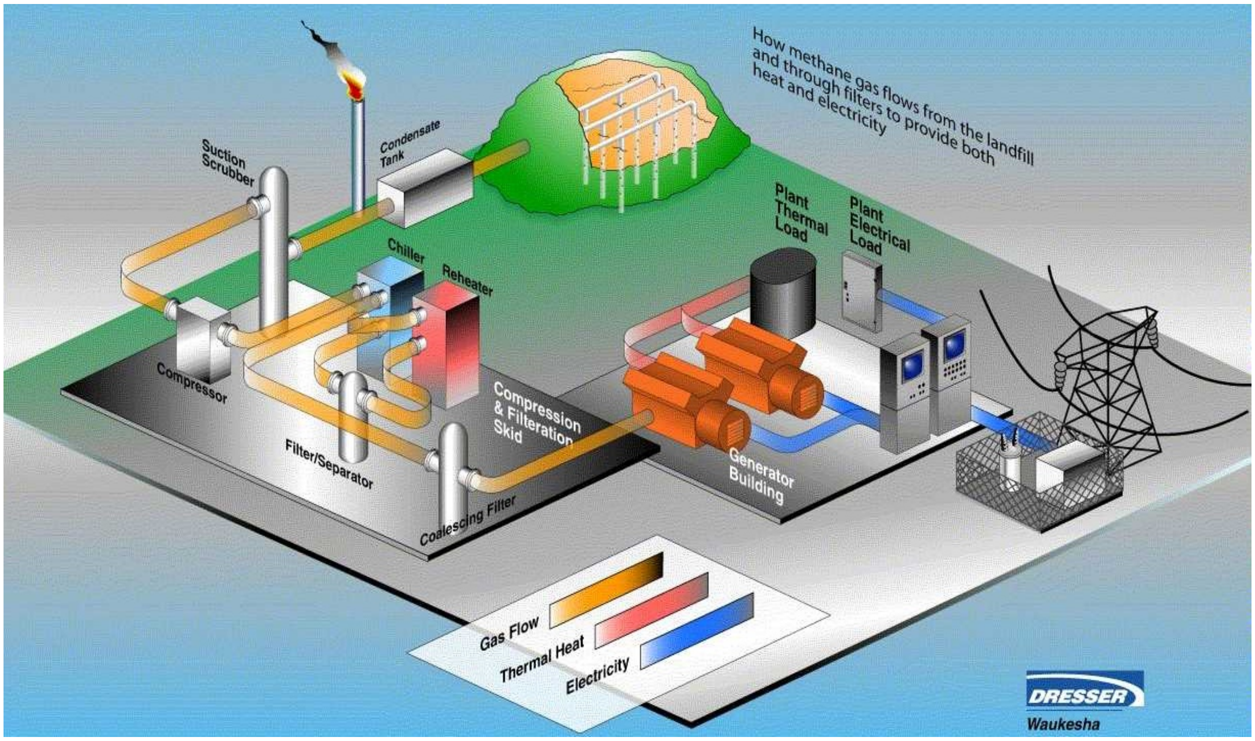
Figure 1-5 presents a diagram of an LFG energy project, including LFG collection, a fairly extensive treatment system and an energy recovery system generating both electricity and heat. Most LFG energy

[5] U.S. EPA LMOP. *LFGcost-Web*, Version 3.5.

[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.

projects produce either electricity or heat, although a growing number of combined heat and power (CHP) systems produce both.

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. For more information about design and installation practices based on the type of energy project that is planned, see Chapter 7. For more information about O&M practices based on the type of energy project, see Chapter 8.

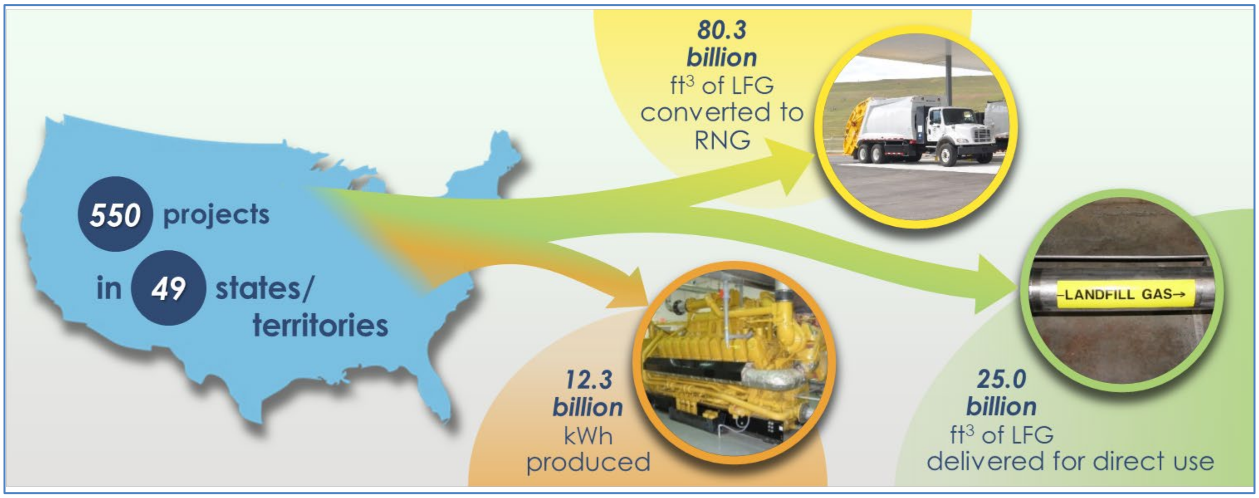
1.4 Uses of LFG

Every million tons of MSW in a landfill is estimated to be able to produce approximately 300 cfm of LFG. Through various technologies, this amount of LFG could generate approximately 0.78 megawatts (MW) of power or provide 9 million Btu per hour of thermal energy.

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.

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 March 2021, 550 LFG energy projects were operating in 48 states and 1 U.S. territory. About 70 percent of these projects generate electricity, while 17 percent are direct-use projects where the LFG is used for its thermal capacity and 13 percent are renewable natural gas (RNG) projects where the LFG is cleaned to a level comparable 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. The majority of RNG projects inject the cleaned gas into a natural gas pipeline. As illustrated in Figure 1-6, the 550 projects are estimated to generate about 12 billion kilowatt-hours (kWh) of electricity, deliver about 25 billion cubic feet of LFG to direct end users and convert about 80 billion cubic feet of LFG into RNG annually.[7] More information about these projects as well as landfills with potential to support LFG energy projects is available from the Landfill and Project Database page of LMOP's website.

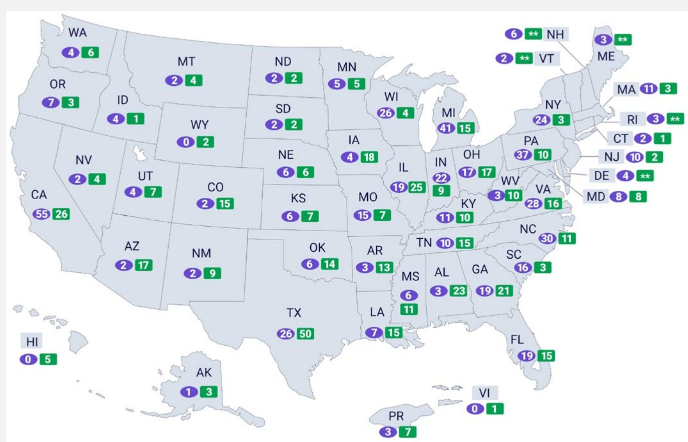
Figure 1-6. Estimated LFG Energy Project Output in the United States (March 2021)



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 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.



7 U.S. EPA. LMOP Landfill and LFG Energy Project Database. March 2021.

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 85 percent) of the LFG energy projects that generated electricity in 2021 used internal combustion engines, which are well-suited for 800-kilowatt (kW) to 3-MW projects. Multiple internal combustion engines 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.

CHP applications, also known as cogeneration projects, provide greater overall energy efficiency. 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.

Direct Use

When fossil fuel prices are high, 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 have been 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 as compared to natural gas.

Direct-use LFG applications are diverse. 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. LFG has also been used 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.

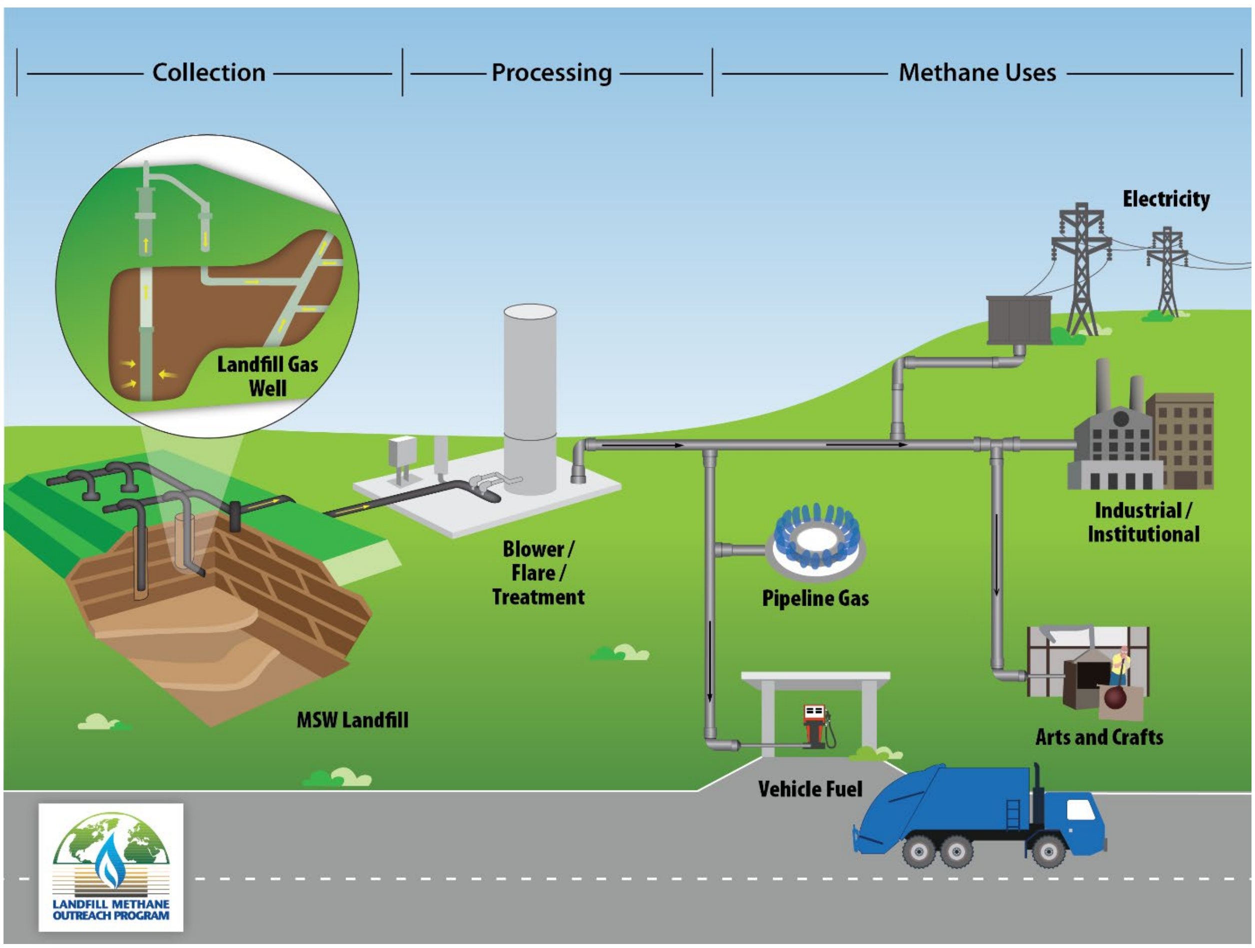
Renewable Natural Gas

The creation of RNG, or pipeline-quality gas, from LFG is not new but has grown in popularity over time. In this process, LFG is cleaned and purified (carbon dioxide and impurities removed) until it is at the quality that can be directly injected into a natural gas pipeline. In some RNG projects, the cleaned gas is directly used as an alternative fuel (for example, compressed natural gas [CNG], liquefied natural gas [LNG] or methanol).

> For more information about electricity, direct-use and RNG technologies, see Chapter 3.

Figure 1-7 graphically depicts some of the potential end use options for LFG energy projects such as generating electricity, providing medium-Btu gas for direct use in heating or other purposes or upgrading the LFG to RNG for transportation fuel or other uses.

Figure 1-7. Example LFG End Use Options



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 greenhouse gas (more than 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 Equivalents[11]

The 550[12] LFG energy projects operational in March 2021 reduce approximately 107.1 million metric tons of carbon dioxide equivalents ($MMTCO_2e$) per year of GHG emissions, which is equivalent to any one of the following:

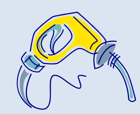
Carbon sequestered by more than 131 million acres of U.S. forests in one year

or

Carbon dioxide emissions from about 12.9 million homes' energy use for one year

or

Carbon dioxide emissions from more than 12.0 billion gallons of gasoline consumed



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 from the power plants, 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.

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8 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019*. U.S. Environmental Protection Agency. EPA 430-R-21-005. April 2021. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019.

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. https://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. March 2021.

- 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, gas pipeline utility or third-party developer, 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), vehicle fuel credits, tax credits or incentives, renewable energy bonds or GHG emissions trading. All these potential revenue sources can help offset GCCS and energy project costs for the landfill owner. For example, if the landfill owner is required to install a GCCS, using the LFG as an energy resource can help pay down the capital cost required for the control system installation.

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.

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 energy 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

CHP 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 beneath 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 provided La Crosse County with new revenue and Gundersen's Onalaska Campus is 100 percent energy independent. The County receives about $175,000 annually from selling LFG while Gundersen earns about $400,000 per year from selling the electricity in addition to saving about $100,000 on annual heating costs.

Examples

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 CHP units at BMW's manufacturing plant in Greer, South Carolina. The project saves BMW approximately $1 million annually in energy costs.

LFG Electricity and Heat in Alabama. Winner of the LMOP 2011 Community Partner of the Year Award, City of Decatur/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 of Decatur brought a second engine online in 2011 for a combined capacity of 1.8 MW. Waste heat from the second engine provides heating to the city's recycling center during the winter.

Stimulating the Local Economy in Kansas. The RNG pipeline injection project at Hamm Sanitary Landfill in Lawrence, Kansas created about five permanent positions on site. In addition, the project's economic ripple effects are estimated to have led to the indirect employment of an additional 20 to 26 people and increased the statewide economic output by $4.3 million. And the project's construction phase was expected to create 50 temporary positions and result in 2,500 local hotel stays and the purchase of more than 6,000 meals.

Table 1-1. Estimated Regional Economic Impacts and Job Creation from LFG Energy Project Construction[13]

Estimated Regional (State-wide) Economic Benefits ***(Economic and job creation benefits are estimates only and are not guaranteed)***	**Typical 3-MW Engine Project**	**Typical 1,000 scfm Direct-use Project** **5-mile pipeline**	**Typical 2,800 scfm RNG Project** **2-mile pipeline**
Direct Effects			
Project expenditures for the purchase of generators, piping, and gas compression, treatment skid and auxiliary equipment	$2.15 million	$1.54 million	$4.35 million
Jobs created	6.0	9.1	15.7
Indirect Effects			
Economic output, resulting from ripple effects	$4.80 to $5.48 million	$3.11 to $3.68 million	$9.66 to $10.94 million
Jobs created, including economic ripple effects	20.3 - 26.1	19.3 - 23.7	43.8 - 55.5

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.

[13] U.S. EPA LMOP. *LFGcost-Web*, Version 3.5.

1.6 Regulatory Framework

Landfills and LFG energy projects can be subject to federal, state and local 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 in Chapter 5. It is important for project developers to review applicable requirements and regulations. Project developers are responsible for ensuring compliance with applicable regulations.

> Links to several state agencies are available on LMOP's State Agencies page.
>
> MSW landfills are required to report GHG emissions and other data if their annual methane generation is greater than or equal to 25,000 metric tons of carbon dioxide equivalents. 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.

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?
- Does the landfill already have a GCS in place?

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/or more arid landfills. Landfills with a GCS in place can calibrate their modeled LFG recovery based on the amount of LFG actually collected. If it is determined that an energy recovery option is viable, then it is important to estimate the amount of recoverable gas that will be available over time. EPA's Landfill Gas Emissions Model (LandGEM) can be used to 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.

> See Chapter 2 for details about modeling and estimating LFG flow.

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, RNG, vehicle fuel or boiler fuel. 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 Landfill Gas Energy Cost Model *(LFGcost-Web)* can help with preliminary economic evaluation. If a GCS is already installed, this improves the economics for a project.

See Chapter 3 for details about project technology options.
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 Requests for Proposals (RFPs).

Chapter 5 provides an overview of the types of contracts used for LFG energy projects.
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 and other environmental attributes. The contract also establishes each partner's responsibilities, including design, installation and O&M. Contracting with a developer is a complex issue and each contract will depend on the specific nature of the project and the objectives and limitations of the participants.

See Chapter 5 to learn about LFG energy project 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 the commodity (e.g., gas, power) to be delivered by the project owner to the end user and the price to be paid by the end user for that commodity. 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, 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 various 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 page.

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.
See Chapter 7 for information about GCS design and Chapter 8 for information about GCS O&M.

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.