

Landfill Gas-to-Energy in the United States

By John Gullledge and John Cosulich

Los Angeles County Sanitation Districts

P. O. Box 4998

Whittier, CA 90607

Tel: (562) 699-7411

Fax: (562) 692-2941

E-mail: jgullledge@lacsds.org

jcosulich@lacsds.org

Abstract. Over 200 landfill gas-to-energy (LFG-E) facilities are currently operating in the United States (US). With the exception of a few research and development projects, essentially all LFG-E facilities are commercial (for profit) facilities. The LFG-E industry in the US has grown by about 11-14% per year over the past five years. There are over 130 LFG-to-electricity facilities, over 40 medium BTU (50% methane) LFG sales projects, over 10 leachate/condensate evaporation projects, and about 10 LFG-to-natural gas projects. The cumulative capacity of the LFG-E-to-electricity projects is about 600 megawatts (MWe). The sale of medium and high BTU LFG is equivalent to over 150 MWe.

Technologies to utilize landfill gas to generate electricity or to displace fossil fuel have been proven in field service over the past 20 years. A competitive market has been created by landfill owners desiring to utilize their landfill gas and by several LFG-E developers. A review of existing projects by State and by year shows that when energy prices are sufficient, landfill gas projects are quickly developed. Low wholesale electricity and fossil fuel pricing are the primary impediment to developing additional LFG-E facilities.

This paper presents a summary of an extensive survey of the LFG-E industry that was completed in early 1997 in conjunction with the Solid Waste Association of North America (SWANA) and the US Environmental Protection Agency (EPA)⁴. A brief survey was conducted in late 1998 to provide more up-to-date information for the ANACON conference.

Introduction. Landfill gas (LFG) is produced by the natural biological decomposition of organics in landfills. Between 20% and 50% of the organics in modern landfills are converted to methane and carbon dioxide over a period of about 30 years. Extensive networks of wells and trenches spaced 150 to 300 feet apart over the entire surface of the landfill are used to collect the gas.

Collecting and utilizing LFG benefits the environment by significantly reducing methane emissions (a significant greenhouse gas) and reducing odors. Without LFG utilization, LFG collection is an environmental control expense. Landfill gas-to-energy (LFG-E) projects provide economic incentives to fully collect and utilize LFG for energy sales revenues. Several technologies have been adapted or developed over the past 20 years to cost effectively utilize LFG.

The cumulative and projected growth of the LFG-E industry is shown in Figure 1. As of the end of 1996, there were over 140 electrical generation facilities with an installed electrical generating capacity of over 520 MWe. Also at this time, landfill gas sales displacing fossil fuels were equivalent to over 140 MWe of power generation. LFG-E projects that are no longer operational have been excluded from Figure 1.

Operational Facilities. Figure 2 shows the number of operational LFG-E facilities on a state by state basis as reported in the 1997 SWANA/EPA survey⁴. Facilities in construction and advanced planning in late 1996 are shown in parentheses. The development of LFG-E facilities correlates with States that have, or have had, favorable energy rates vs. state population and the resultant waste generation.

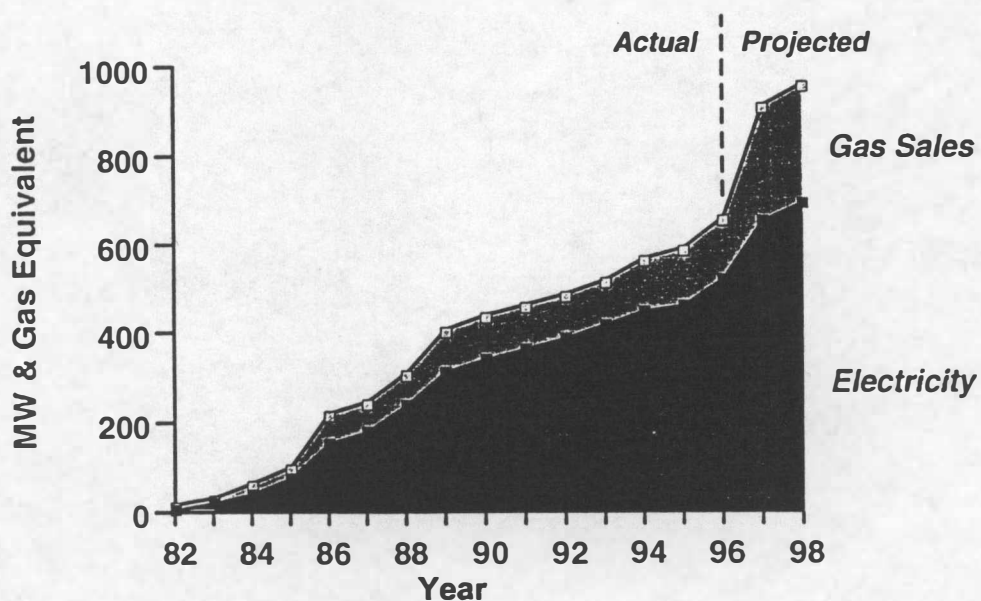


Figure 1 - Landfill Gas Utilization Capacity Over Time (from reference 4)

California offered very favorable energy contracts in the early 1980's, over \$0.08/kilowatt-hour, for renewable energy. The result was that over 30 LFG-E facilities were built by 1990 in California. When the favorable energy rates expired and energy rates dropped to \$0.03/kwhr, few LFG-to-electricity projects were developed.

Other states that offered high electrical purchase rates for renewable power attracted relatively high numbers of LFG-E facilities including Illinois, Michigan, New York and New Jersey. A review of existing projects by State and by year shows that when energy prices are sufficient, landfill gas projects are quickly developed.

Future Growth - Facilities in Construction and Advanced Planning. There is still a large growth potential in the US considering there are over 4,000 landfills and only about 200 LFG-E facilities. The EPA estimates that about 700 landfills in the US are large enough to support economically feasible LFG-E facilities. However, the expiration of the Section 29 tax credits is expected to slow the development of additional LFG-E facilities. Low prices for electricity and fossil fuels in the US impede the development of more LFG-E facilities.

Closed Landfill Gas-to-Energy Facilities. Over 40 landfill gas-to-energy facilities have closed since the 1970's. In general, closures result from a combination of adverse events. These shutdowns provide historical lessons on the risks associated with developing landfill gas projects. The common causes of plant closures in general order of occurrence are:

- Insufficient landfill gas
- Higher than anticipated O&M costs
- Falling energy rates
- Energy customer moved or shutdown
- Relocated LFG-E plant to another landfill
- Gas rights contract expired
- Favorable Energy Pricing Period Ended
- Power Purchase Agreement Sold

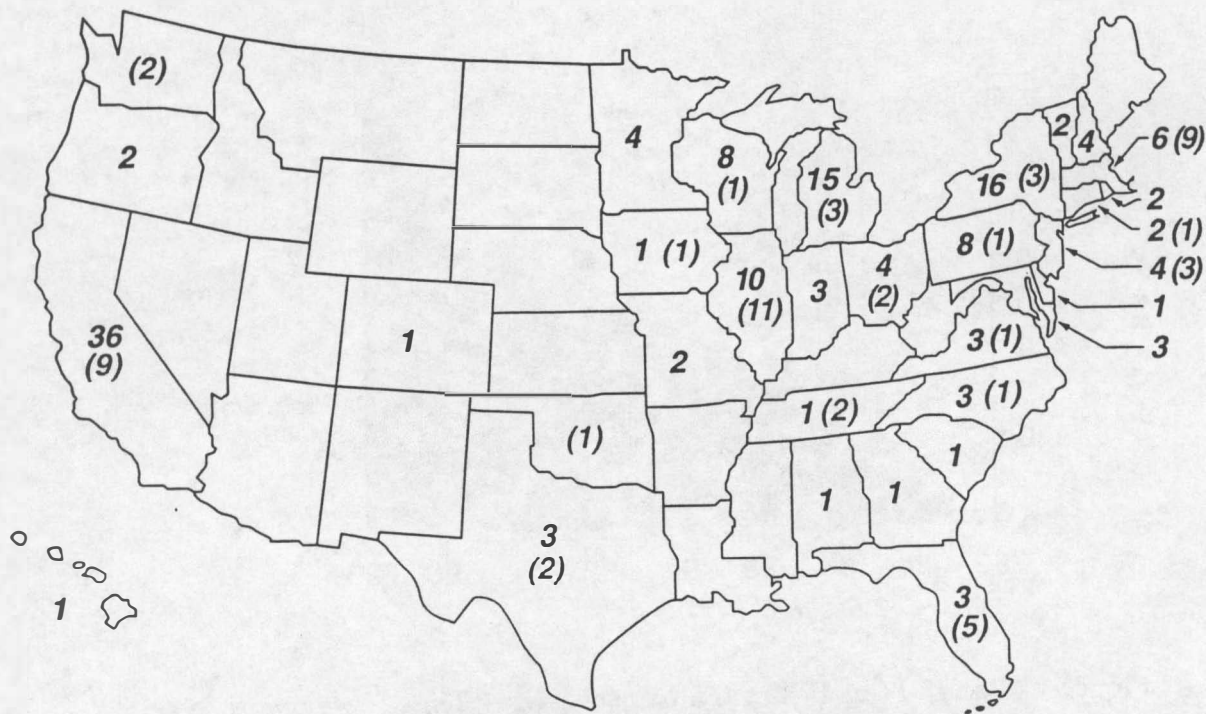


Figure 2 – Existing and Planned Landfill Gas-to-Energy Facilities in the United States at the end of 1996 (from Reference 4)

Power and Fuel Costs Required for Cost Effective Development of LFG-E Projects. Estimates of the cost of converting landfill gas-to-electricity vary significantly, primarily with project size. In general, the larger the LFG-E facility, the lower the production cost. According to LFG-E developers, about 4.5 cents/kilowatt-hour (kwhr) is typically needed to develop new LFG-to-electricity projects. Over the past several years this production cost has remained relatively constant because of improved technology and improved expertise within the industry.

When a developer secures an energy contract plus tax credits that exceed his generation costs and economic return rate, he generally proceeds. A historical examination of the development of LFG-E facilities shows that there is a very strong correlation between energy prices and landfill gas development both in terms of location and timing. When favorable energy rates are available, LFG-E facilities are quickly developed in that area if suitable landfills are available. A state by state analysis confirms this correlation between electricity pricing and the development of LFG-E facilities.

An alternative to using LFG for electrical power generation is to sell the LFG as a fuel. Facilities that process LFG to natural gas standards to utilize existing natural gas pipelines are generally referred to as “high BTU” facilities. The US has an extensive network of natural gas (over 90% methane) pipelines throughout most of the country. According to the industry experts, high BTU projects can be developed LFG-E facilities at large landfills with natural gas pricing of about \$2.50 per million BTU or higher.

Pending Electrical Legislation. Pending legislation by the US Congress on the deregulation of electrical utilities may allow LFG-E facilities to sell electricity directly to end users. The US Federal government is considering laws requiring large electrical utilities to purchase a specified minimum percentage of renewable power. Both of these initiatives may encourage additional LFG-E development.

Tax Credits. The US Federal government provides tax credits of about \$1.05 per million BTU for qualifying energy facilities. These federal tax incentives are generally referred to as “Section 29 tax credits” and are

available to landfill owners or owners of the gas collection facilities provided the facilities were installed by June 30, 1998. Section 29 tax credits may provide the economic incentive to proceed on marginal projects.

Regulatory Requirements. Numerous government and regulatory agencies in the US require gas collection at landfills that meet specified criteria. At the Federal level, the March 12, 1996 promulgation (FR Vol. 61, No. 49) of the Clean Air Act (CAA) requires landfill gas from about 400 to 500 of the largest landfills (over 2.5 million megagrams) be collected to control landfill gas emissions.⁴

The environmental benefits of LFG-E are large. Landfills are estimated to be the largest man made emissions source of methane in the US. Methane is a potent greenhouse gas that has 21 times the warming effect of carbon dioxide. The collection and utilization of landfill gas benefits the environment by not allowing methane to be vented to the atmosphere. The US EPA has estimated that for the CAA regulations published in March 1996, that the associated greenhouse gas reduction is equivalent to 2 billion gallons of gasoline or taking 4 million cars off the road⁴.

Several local areas have required landfill gas collection for many years. For example, in Los Angeles, the South Coast Air Quality Management District has required landfill gas collection since the mid-1980's even at small to medium size landfills. More recently, many additional state and local agencies have been implementing regulations requiring landfill gas collection.

Survey Approach and Terminology. The 1997 Survey⁴ identified LFG-E projects by reviewing previous surveys, and calling developers, operators, and landfill owners to ask for updates. Equipment manufacturers were also contacted to provide lists of equipment sold to landfill customers. Information was solicited on a voluntary basis. Information on tentative projects (without signed contracts) was excluded. Several developers indicated they had secured the rights to gas at many landfills and were in the process of negotiating energy sales agreements. Since this approach may have missed several LFG-E projects, the terms "about" and "approximately" are used throughout. At least one major company has a policy of not releasing information on LFG-E facilities which resulted in the omission of their LFG-E facilities from this survey.

The term "project" is defined as the number of different technologies employed at a site to beneficially utilize landfill gas. For example, if reciprocating engines are added to a landfill incrementally, the added engines are counted as part of the original project. Alternately, if a new boiler/steam turbine plant is added to a landfill using reciprocating engines, the new boiler/steam turbine plant would be counted as a separate project.

Often continuous landfill gas BTU readings are not available. The default value of landfill gas is assumed to be 50% methane or 500 BTU/ft³. To compare electrical generation with landfill gas sales, a heat rate of 11,000 BTU/kwhr is used. Accordingly, a landfill gas sale of 1 million standard cubic feet/day (MMSCFD) is equivalent to 1900 kilowatts of power production.

Technologies for Landfill Gas Utilization. Landfill gas can displace natural gas and other fossil fuels in many applications. Most operational LFG-E projects generate electricity. Electrical generation technologies include reciprocating engines, gas turbines, boiler/steam turbines, and combined cycles (gas turbine and steam turbine). The usage of these technologies by the LFG-E industry is shown in Table 1.

Reciprocating Engines. About 60% of LFG-to-electricity facilities use reciprocating engines for electrical power generation. Caterpillar (CAT) is the number one supplier of reciprocating engines on landfill gas in the US. There are about 250 CAT engines operating or planned for LFG facilities. The CAT-3516, which first appeared in 1988 is rated at 800 kw per engine. The CAT-3516 is the most prevalent engine used in the LFG-E industry. The newer CAT 3600 series engines, commercially available since 1996, offers higher efficiency and lower emissions in comparison to the CAT-3500 series.

Technology	Operational Facilities	Capacity Range of Installed Facilities (kw) or Equivalent	Comments
Reciprocating Engines	100+	80-12,300	Many developers.
Gas Turbines	25	740 -16,500	Primarily operated by WMI and Gas Recovery Systems
Combined Cycle	3	13,600-20,500	All installed by BFI.
Boiler/Steam Turbine	6	7,000-50,000	Mostly in Southern California.
Medium BTU	40+	300 - 17,000	Many developers. Gaining popularity.
High BTU/Vehicle Fuel	10	800 -19,000	Primarily GSF/ Ecogas
Leachate/Condensate Evaporators	10+	1,000	Can significantly reduce the cost of liquids disposal.

Table 1 - Landfill Gas Utilization Technologies as of Late 1998

Waukesha is second in market share with over 50 engines, primarily 7042 series rated at over 1,000 kw each. BFI uses Waukesha extensively. Early LFG-E facilities in 1984-1986 by Pacific Energy, Getty, and Laidlaw used primarily Cooper-Superior engines. One early facility in New York State uses 52 Cummins engines to generate about 6,000 kw. All four of these engine manufacturers are based in the US. There are also several foreign engine suppliers including MWM Deutz and Jennbacher, with LFG fired engines in the US.

Several LFG-E developers have standardized on CAT engines. Standardizing on one engine manufacturer allows an operator to both reduce spare parts inventories and improve staffing flexibility. Several developers are using a modular approach using multiple reciprocating engines per site, and installing and removing power generation capacity to match the landfill gas flow. This is an excellent method of reducing costs in what is considered to be a capital-intensive industry.

Gas Turbines. Gas turbines are extremely popular in the independent power industry for plants from 10 MWe to over 100 MWe. Improvements in materials including ceramic blading will make gas turbines even more attractive to the landfill gas industry in coming years. Gas turbines are competitive for power generation facilities over 5 megawatts. There are over 35 gas turbines operating on landfill gas. Over 30 of these gas turbines were manufactured by Solar Turbines, Inc., a CAT subsidiary.

Waste Management, Inc. (WMI), has the most extensive reciprocating engine and gas turbine experience with landfill gas. WMI recently published a paper with operating costs of both gas turbines and engines. The gas turbines cost less to maintain, yet are less efficient. WMI has selected the new CAT 3600 series reciprocating engines for all their 1997 LFG-E projects. WMI reported total costs for reciprocating engines and gas turbines are "close" for large landfills.

Combined Cycles. Combined cycle (CC) facilities are very popular in the independent power industry for power plants over 20 MWe. This technology offers highest efficiency, but at a higher capital cost per kw. Only Browning-Ferris Industries (BFI) has installed CC facilities fueled exclusively by landfill gas.. CC facilities are only cost effective at very large landfills. The combined capacity of operating CC facilities is about 55 MWe.

Boiler/Steam Turbines. There are six boiler/steam turbine plants in the US using solely LFG, mostly in southern California. The boiler/steam turbine technology is only effective at very large landfills with sufficient landfill gas for over 10 MWe–20 MWe. Boilers have the lowest NO_x emissions of any technology, which is a significant reason all of these plants are in the Los Angeles area, an area with stringent air regulations. These existing plants account for over 100 MWe of capacity. One additional 10 MWe facility is planned in New Jersey.

Medium BTU Applications. “Medium BTU applications” are defined as projects piping relatively unprocessed LFG, typically about 500 BTU/ft³, offsite to a large energy user. Medium BTU projects normally include minimal processing, including only filtration and dehydration. There are currently about 40 medium BTU projects in the US. In most cases LFG is used to displace fuel oil, natural gas or other fossil fuel in a boiler or kiln. When a utility power plant or an industrial user(s) is located within several miles of a landfill, it may be feasible to pipe landfill gas to their boilers. This assumes the industrial user has a large enough gas demand and a suitable load profile. Medium BTU projects are even feasible at small landfills if a suitable industrial user is nearby.

High BTU Applications. There are about ten high BTU plants in the US, primarily by Ecogas/Getty Synthetic Fuels (Ecogas). Over the years, Ecogas has refined their LFG processes and can now process LFG to achieve natural gas pipeline specifications for less than \$2.50 per million BTU at large landfills.

Leachate and Condensate Disposal. Leachate and LFG condensate treatment and disposal can be an expensive part of landfill ownership. Many landfills do not have sewer connections. Landfill gas can be used to evaporate liquids in flares or specialized vessels. Several vendors offer leachate and condensate evaporators. Over 10-leachate/condensate evaporation systems are estimated to be operational as of October 1998.

Should Landfill Gas-to-Energy Projects be Outsourced? The gross annual revenues of the LFG-E industry are estimated at between \$250 and \$400 million per year. This is relatively small compared to the solid waste management industry which is estimated at over \$40 billion per year. Also, the skills required to develop and operate LFG-E facilities are significantly different from the skills that are required to operate a landfill. Many landfill owners view the LFG-E industry as a non-core business that can be outsourced. Most LFG-E facilities are developed by independent companies that specialize in LFG-E facilities. Only two large private waste-management companies, WMI and BFI, have internal LFG-E groups.

On publicly owned and operated landfills, only a few public agencies have the staffing and the in-house expertise to develop their own LFG-E facilities. Accordingly, most public agencies have elected to use private developers to construct and operate LFG-E facilities at their landfills.

Several independent LFG-E developers are actively contacting landfill owners to contract landfill gas rights and to develop LFG-E projects. LFG-E developers are typically specialists who focus on the utilization of landfill gas and tax benefits as opposed to landfill owners who focus on refuse disposal and landfill operations. There is strong competition for LFG-to-electricity projects. However, the competition for high BTU applications is limited.

Returns to Landfill Owners. In the early 1980's when energy prices were higher, LFG-E developers often offered landfill owners 10 to 15% of gross revenues in exchange for gas rights. Decreasing prices for electricity and natural gas have forced LFG-E developers to become more efficient as well as reduce payments to the landfill owners. Currently, LFG-E developers typically offer to install and operate the gas collection system at their costs. Depending on the size of the landfill, the landfill owner can save millions of dollars in avoiding the cost of installing, operating, and maintaining a gas collection system for his landfill by contracting with a LFG-E developer. At large landfills, landfill gas may sell at \$0.50/MMBTU.

Conclusion. Technology to convert landfill gas to electricity or to displace fossil fuel is proven and available. A competitive market has been created by landfill owners desiring to utilize their landfill gas and by several LFG-E developers. A review of existing projects by State and by year shows that when energy prices are sufficient, landfill gas projects are quickly developed.

Landfill size and the local pricing of electricity and fossil fuels are the primary determinants of whether LFG-E facilities are developed or if the landfill gas is flared. LFG-E facilities are built for commercial purposes, and typically require a minimum of \$0.045/kwhr or \$2.50/MMBTU for development.

Landfill gas-to-energy projects provide many benefits. Environmental benefits of LFG-E projects include dramatic decreases in greenhouse gases, elimination of almost all landfill gas associated odors, and conservation of fossil fuels. Economic benefits include economic returns to the landfill owners and project developers, additional local jobs, and reduced dependency on imported oil.

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