Report

Comparison of Potential Electricity Production from RDF and LFG

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Ramsey/Washington Counties Resource Recovery Project

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Ramsey/Washington Counties
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Contents

Page

Appendices

Executive Summary

This analysis compares the potential electricity production from Municipal Solid Waste (MSW) using either a Refuse-Derived-Fuel (RDF) technology or Landfill Gas (LFG) technology.

Potential LFG generation from decomposing landfilled MSW was estimated for the Ramsey/Washington County Resource Recovery Project (Project) based on waste composition data supplied by the Project.

The LFG generation rate is the total volume of LFG generated over the entire decomposition period. In a standard Subtitle D sanitary landfill, MSW decomposition and thus LFG generation typically extends over a period of 20 to 25 years. "New" bioreactor technology, which optimizes the amount of moisture in the landfilled MSW, speeds up MSW decomposition and, thus LFG production. It is important to note, however, that bioreactor technology merely speeds up the rate at which the total available amount of LFG is produced. No technology can increase the maximum amount of LFG available from a unit of MSW.

LFG production estimates ranged from 0.40 cubic feet per pound of MSW to a theoretical maximum of 6.10 cubic feet per pound of MSW with the specific MSW composition reported for the Project

In this analysis, a conservative value of 3.66 cubic feet of LFG per pound of MSW was used given the theoretical maximum based on the composition of the MSW stream

Conversion of LFG to usable energy can take several forms. The most common method is to use an internal combustion engine that burns LFG to power a generator to produce electricity. This method requires 750 tons of MSW to be disposed in a landfill to produce enough electricity to power one home for 20 years. If the theoretical maximum LFG production (although not yet attained in actual application) were achieved, production of the same amount of electricity would require 455 tons of MSW.

An RDF facility processes MSW to produce a fuel, which is burned in a combustion facility to produce electricity. This technology is used by NRG Energy, Inc. at their plant in Newport, Minnesota. Eleven (11) tons of RDF must be burned in order to produce enough electricity to power one house for one year. It will take 14 tons of MSW to produce the 11 tons of RDF. To power a single home for 20 years using RDF will therefore require 280 tons of MSW.

In summary, meeting demands for home electricity use through LFG production requires considerably more MSW (1.6 to 2.7 times more over a 20 year period) than does generating electricity through burning RDF. If considered over a single year of the 20-year period, the ratio increases to between 32 and 54 times more MSW input for LFG production.

This difference is due to different factors including the differing contributions of certain components of the MSW stream. For example, a plastic container won't contribute to the production of LFG but contributes significantly to the fuel value of RDF.

1. Introduction

Mr. Norm Schiferl, Ramsey County Department of Public Health, requested the following analysis of electricity production from municipal solid waste (MSW) landfill gas (LFG) production. The analysis drew on data from the 1999 MSW Composition Study completed by R.W. Beck for the Solid Waste Management Coordinating Board. The composition data used are summarized in Table 1-1.

Table 1-1

MSW Composition

Item	1999 Study Percent	Decomposable Percent	EPA 1999 Generation[3]
Paper	34.2%	34.2%	38.1%
Plastic	11.0%	0%	10.5%
Metals	4.4%	0%	7.8%
Glass	2.7%	0%	5.5%
Organic Materials	27.3%	17.2%[1]	28.3%
Other Waste	18.3%	2.4%[2]	6.6%
Problem Materials	1.8%	0%	3.2%
HHW/HW	0.3%	0%	0%
	100%	53.8%	100%

[1] Assumes only grass/leaves, food waste, diapers and other organics will degrade to form methane. Wood wastes typically decompose too slowly for significant methane generation.

[2] Textile waste only

[3] USEPA website http://www.epa.gov/epaoswer/non-hw/muncpl/facts.htm

The following pages examine various methods for estimating LFG production in conventional landfills. LFG production in bioreactor landfills is estimated on the limited data available from active facilities.

2. Landfill Gas Generation

2.1 Maximum Achievable Landfill Gas Production[1]

Organic material placed in anaerobic (i.e., oxygen-free) conditions typically decomposes to produce LFG. The chemical reaction that occurs can be shown as:

$$\text{Organic matter} + H_2O \xrightarrow{\text{Bacteria}} \begin{array}{l}\text{Biodegraded}\\ \text{Organic}\\ \text{Matter}\end{array} + CH_4 + CO_2 + \text{Trace Gases}$$

In their book on integrated solid waste management engineering principles, Tchobanoglous, et.al. describe methods to use MSW composition to estimate LFG production. Using the composition of MSW provided in Table 1-1 and assuming 20 percent moisture content, which is an accepted average for MSW, the chemical formula for LFG production is:

$$C_{41}H_{64}O_{29}N + 9.75\,H_2O \longrightarrow 20.875\,CH_4 + 20.125\,CO_2 + NH_3$$

The theoretical maximum amount of LFG that can be produced under this formula is 6.10 cubic feet/pound of MSW disposed (see Appendix A). However, the theoretical maximum assumes total breakdown of the organic portion of the MSW. Because most landfills are "dry" (i.e., designed to limit the infiltration of moisture), this value tends to over estimate the volume of collectible LFG.

It is also important to note that the total volume of LFG available in a pound of MSW is likely to be produced over a period of 20 to 25 years. Furthermore the generation rate of LFG is not a constant over the 20 to 25 year cycle. Rather, LFG generation tends to peak early in the cycle (say in 5 to 10 years) and then tapers until all decomposable material is converted and/or moisture is exhausted.

The theoretical maximum production of LFG assumes adequate moisture is present to complete the chemical reaction. In a conventional "dry" landfill, sufficient moisture does not exist to complete the chemical reaction. As noted above, this is a result of deliberate efforts to minimize moisture infiltration. Typically, even bioreactor landfills have a difficult time adding and controlling moisture to optimize organic degradation. This difficulty can be attributed to preferential flow paths (i.e., inconsistencies in MSW composition that cause moisture to be distributed unevenly), plastic bags that shield organics from moisture, and internal landfill temperatures that reduce the speed of the chemical reaction.

The result of either of these factors — LFG generation that peaks early and then tapers off or less moisture than needed to complete degradation — is that a conventional landfill is likely to produce LFG at levels below the theoretical maximum.

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[1] Tchobanoglous G., H. Theisen and S. Vigil. Integrated Solid Waste Management, Engineering Principles and Management Issues. McGraw-Hill, New York. 1993.

2.2 USEPA Gas Estimation Methods[2]

The USEPA offers three basic methods to estimate LFG production at a conventional landfill site. The first two methods can be completed using "desktop" evaluations and minimal site-specific information. Because the third method requires on-site testing (test wells and pumping), it was not considered in this analysis.

The first USEPA method is a simple approximation, which assumes a LFG generation rate of 0.10 cubic feet per pound of MSW per year. The actual value can vary from 0.05 to 0.15 cubic feet per pound of MSW per year. Typical LFG production from MSW can extend from 20 to 25 years after initial disposal. Thus, using this method, LFG production, could range from[3] a low of 1.00 to 1.25 cubic feet per pound of MSW disposed to a high of 3.00 to 3.75 cubic feet per pound of MSW disposed, with an average of 2.00 to 2.50 cubic feet per pound of MSW disposed.

The USEPA's second method is the "first order decay model," which accounts for the time variance in gas generation. Landfills can produce gas for as long as 50 years depending on MSW composition and moisture, though as noted above, typical LFG production lasts 20 to 25 years. The calculated values for LFG generation potential range from 3.43 to 3.88 cubic feet per pound of MSW disposed depending on the amount of moisture available. The higher the moisture content, the higher the generation potential.

2.3 Other Sources and Bioreactor Technology

Several other estimates and sets of observed and published data are available and can be used to quantify LFG production from landfilled MSW. Oweis and Khera[4] observed LFG production that ranged from 0.02 cubic feet per pound of MSW per year for typical landfills to 0.20 cubic feet per pound of MSW per year for landfills with a high moisture content. They caution the estimates may be off by an order of magnitude depending on the moisture conditions in the landfill.

Reinhart and Townsend[5] examined bioreactor and conventional landfills. Their research at a landfill in Alachua County, Florida indicated the portion of the site where leachate was recirculated produced 0.375 cubic feet per pound of MSW per year and the dry portion of the landfill produced 0.15 cubic feet per pound of MSW per year of LFG. These measurements are not considered representative of LFG production over time. The measurements represent one time tests in specific locations in a specific landfill and are not reflective of the typical 20 to 25 year LFG generation cycle. Therefore, the values presented should not be considered representative of total potential LFG generation for either a conventional or a bioreactor landfill.

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[2] United States Environmental Protection Agency, Turning A Liability Into An Asset, A Landfill Gas-To-Energy Project Development Handbook. EPA 430-B-96-0004. 1996.

[3] Calculations: Low 0.05x20=1.00, 0.05x25=1.25; Avg 0.10x20=2.00, 0.10x25=2.5; High 0.15x20=3.00, 0.15x25=3.75.

[4] Oweis, I.S. and R. Khera. Geotechnology of Waste Management. PWS Publishing Company, Boston. 1998.

[5] Reinhart, D.R. and T. Townsend. Landfill Bioreactor Design and Operation. Lewis Publishers. Boca Raton, Florida. 1998.

3. Summary of Landfill Gas Generation Potential

Table 3-1 summarizes the various methods of estimating LFG generation potential described above.

Given the ranges of potential generation and the theoretical maximum shown, Foth & Van Dyke will use a LFG generation value of 3.66 cubic feet per pound of MSW for additional analysis. This value is representative of expected generation given a theoretical maximum of 6.10 cubic feet per pound of MSW for Ramsey/Washington Counties.

Table 3-1

Summary of Landfill Gas Generation Potential

Source/Description	Generation Potential (ft^3/lb of MSW) Low	 Average	 High
Theoretical Maximum[1]	--	--	6.10
USEPA, Approximation	1.00	2.25	3.75
USEPA, First Order Decay	3.43	3.66	3.88
Oweis & Khera, Observed	0.40	2.70	5.00

[1] Using Tchobanoglous, et al., methods applied to Ramsey/Washington Counties waste composition. See Appendix A.

4. Landfill Gas Energy Potential

Because the goal of this analysis is to determine the amount of electricity potentially available in MSW, methods to convert LFG to electricity must also be examined.

The first step in converting LFG to usable energy is to collect the LFG. Collection system designs and recovery efficiency vary by site. For this analysis, the key factor is collection system efficiency. The USEPA reports LFG collection efficiencies range from 50 to 90 percent, with a reasonable assumption being 75 to 85 percent[6] efficiency. For this analysis, Foth & Van Dyke assumed a collection efficiency of 80 percent.

The heating value of LFG is reported in several sources and ranges from 400 Btu/ft^3 to 600 Btu/ft^3. For LFG to energy projects, the USEPA provides an estimated heating value of 450 Btu/ft^3.[6]

Using an 80 percent collection efficiency and a heating value of 450 Btu/ft^3, one pound of MSW should yield 2.93 cubic feet of LFG (3.66 ft^3 x 0.80 = 2.93ft^3) or 1,318.5 Btu (2.93ft^3 x 450Btu/ft^3 = 1,318.5 Btu) over the biological decay life of the MSW (20 to 25 years). The theoretical maximum value would be 4.88 cubic feet of LFG (6.10ft^3 x 0.80 = 4.88 ft^3) or 2,196 Btu (4.88ft^3 x 450 Btu/ft^3 = 2,196 Btu) over the biological decay life of the MSW.

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[6] United States Environmental Protection Agency, Turning A Liability Into an Asset, A Landfill Gas-To-Energy Project Development Handbook. EPA 430-B-96-0604. 1996.

5. Energy Conversion

Several methods to convert LFG to useable energy such as electricity, steam, boiler fuel, vehicle fuel or pipeline quality gas exist. Each method has advantages and disadvantages depending on the quantity, quality, and source of LFG, end use locations, and other factors.

An internal combustion engine is the most common method of converting landfill gas to useable energy. Gross daily electrical power generation of an internal combustion engine is calculated as:

kW = gas flow x Energy x
1/Heat Rate

Where gas flow is measured in ft^3/day, energy content is measured as Btu/ft^3, heat rate is measured as kWh/Btu, and 1 day is equal to 24 hours.

For our analysis and using data from previous sections, this can be shown as:

One pound of MSW yields 2.93 cubic feet of LFG over 20 years

$2.93ft^3 \div \{20 \text{ yrs x } 365 \text{ days/yr}\} = 0.0004 \text{ ft}^3\text{/day}$

Heat rates for internal combustion engines are typically 12,000 Btu/kWh.

Gross power generation = 0.0004 ft^3/day x 450 Btu/ft^3 x 1/12000 Btu/kWh x 1 d/24 hrs

Or <u>gross power generation = 6.27×10^{-7} kW</u>.

Further adjustments are needed to account for energy lost during generation and equipment downtime. Assuming a 2 percent parasitic load (typical) and 90 percent equipment availability, the net power generation is 5.53×10^{-7} kW

<u>$6.27\text{x}10^{-7}$ kW x 0.98 x 0.90 = $5.53\text{x}10^{-7}$ kW</u>

Therefore the annual electricity generated is 0.0048 kWh per pound of MSW disposed each year

$5.53\text{x}10^{-7}$ kW x 365 days x 24 hrs/day = 0.0048 kWh

and total energy potential over 20 years equals 0.096 kWh

0.0048 x 20 yrs = 0.096 kWh per pound

This can also be reported as 1 ton of MSW produces 192 kWh

0.096 kWh per pound X 2,000 pounds = 192 kWh per ton

The maximum theoretical production rate given the same conditions would be 9.21×10^{-7} kW or 0.1617 kWh per pound of MSW disposed over 20 years (i.e., 323.4 kWh per ton).

Since the average home uses 7,200 kWh per year[7], one home would require 144,000 kWh over a 20-year LFG production cycle. Applying the results of the previous calculations, a total of 750 tons of disposed MSW would be required to produce enough LFG converted to electricity to power the average home for 20 years.

$$144{,}000 \text{ kWh} \div 0.096 \text{ kWh/lb refuse} \div 2{,}000 \text{ lbs/ton} = 750 \text{ tons}$$

Using the maximum theoretical LFG production and conversion estimates, 445 tons of MSW would be required to produce enough LFG converted to electricity to power the average home.

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[7] Data provided by Xcel Energy.

6. Summary

The most LFG that could be produced by a conventional landfill receiving MSW with composition equal to that by Ramsey and Washington Counties is 6.10 cubic feet per pound of MSW disposed. This value is called the theoretical maximum. Not all organic waste will decompose in a landfill, in part because conventional landfill design and operations are intended to limit the quantity of moisture present. Therefore, the more realistic LFG production rate is estimated to be 3.66 cubic feet of LFG per pound of MSW disposed.

An estimated 750 tons of MSW must be landfilled to produce the LFG that, when converted to electricity using an internal combustion engine, provides enough electricity to power one home for 20 years. If LFG could be generated and collected using theoretical maximums, the quantity of landfilled MSW needed would drop to 445 tons.

By comparison, NRG reports approximately 11 tons of RDF (produced from approximately 14 tons of MSW) are needed to produce enough electricity to power a home for one year[8]. Over a 20-year period, 280 tons of MSW would need to be processed into RDF to produce enough electricity to power the same home. In short, considerably more MSW (2.7 times) is needed to produce the electricity from LFG than from RDF. Even if the theoretical maximums could be achieved, which has not yet happened, LFG requires 1.6 times more MSW to produce the same amount of electricity as RDF over a 20-year period.

One reason for this difference is the difference between the energy content and the potential to degrade of certain MSW stream components. For example, the energy content of mixed plastics is approximately 14,000 Btu/pound, but plastic has no LFG generation potential[9].

In summary, it takes a prolonged period of time to produce and capture the energy content of MSW via LFG production while energy production from RDF production is more rapid. In any given year, RDF technology can use 14 tons of MSW to produce the same energy available from recovering the LFG generated by 750 tons of MSW. This is an annual factor of 54 times more MSW required to produce equivalent energy from LFG. However, the 750 tons in a landfill will continue to provide LFG to produce electricity for 20 years. This reduces the total difference to 2.7 times more electricity from RDF.

If LFG could be produced and recovered at the theoretical maximums, equivalent electricity production would require 455 tons (32 times more MSW than RDF in a single year and 1.6 times more MSW than RDF over the 20 year period).

Another way to consider this is that burying 750 tons of MSW in year 1 has the potential to produce 20 years of electricity for a single home. Conversely, an RDF facility has to receive at least 14 tons of MSW each year over 20 years (280 tons total) to produce electricity to power one home.

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[8] Based on data from NRG for their RDF facilities.

[9] Tchobanoglous, G., H. Theisen and S. Vigil. Integrated Solid Waste Management, Engineering Principles and Management Issues. McGraw-Hill, New York. 1993.

Appendix A

Calculations for Theoretical Maximum Methane Production