Landfill Gas Direct Use in Industrial Facilities

Al Hildreth, General Motors Corporation, Worldwide Facilities Group, 2005

ABSTRACT

Municipal solid waste landfills are the largest source of human-related methane emissions in the United States. Methane is about 21 times more potent than carbon dioxide as a greenhouse gas. The use of landfill gas as a renewable energy source for direct use in boilers and other gas fuel-fired equipment can reduce methane emissions to the environment and offset the use of fossil fuels. As natural gas prices have more than tripled over the last five years, landfill gas can be purchased on a cost effective basis under the correct location and development conditions.

This paper will discuss the criteria that determine the optimum conditions for direct landfill gas use at industrial plants from an environmental, operations, and business perspective. The elements that will be discussed include: plant location in relation to the landfill, types of landfills and gas generation rates, wells and pipeline infrastructure, plant combustion system considerations, project development methods, project implementation considerations, and an example business case.

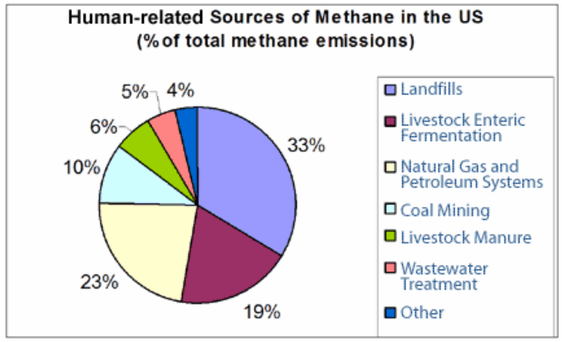
Considering the importance of reducing greenhouse gas generation to the environment and the positive sustainability aspects of Renewable Energy, the cost effective use of landfill gas in industrial facilities is an important initiative that should be pursued. The intended results of this paper are to promote the skills of industry in identifying, developing, and implementing direct use landfill projects.

Introduction

Landfill gas (LFG) is a flammable and potentially harmful gaseous mixture consisting mostly of methane (CH_4) and carbon dioxide (CO_2) with trace amounts of volatile organic compounds (VOC). LFG results mainly from anaerobic decomposition of municipal solid waste that is decomposed in landfills. Gas production begins after deposition and attains peak production in about 10 years (Egolfopoulos, Qin & Tsotsis 2001). The primary constituents in LFG and the contribution of methane from landfills are listed in Table 1 (O'Leary & Walsh 2002; EPA 2003). Municipal solid waste landfills are the largest source of human-related methane emissions in the United States, accounting for about 34 percent of these emissions (EPA 2005). The Global Warming Potential for Methane, according to the United States Environmental Protection Agency (EPA), is about 21 times that of CO_2 which demonstrates the significance of controlling methane emissions where feasible. In addition to reducing Methane emissions from landfills to the atmosphere that currently do not have collection systems and flares, utilizing LFG directly in a combustion system or for electricity generation offsets the use of fossil fuels and further reduces the impact to the environment. Direct use of LFG in combustion processes is twice as efficient as electrical generation with reciprocating engines and will be the focus of this paper; however, if direct use is not feasible, electrical generation is another potentially viable use for landfill gas.

Table 1. Primary Landfill Gas Constituents and Methane Sources

Component	%
Methane	47.40
Carbon dioxide	47.00
Nitrogen	3.70
Oxygen	0.80
Paraffin hydrocarbons (HC)	0.10
Aromatic-cyclic HC	0.20
Hydrogen	0.10
Hydrogen Sulfite	0.01
Carbon monoxide	0.10
Trace compounds	0.50



Source: O'Leary & Walsh 2002; EPA April 15, 2003

To beneficially use LFG competitively requires many technical and commercial considerations including—identification of a viable landfill, environmental benefits and permitting, quality of LFG, combustion system design, and a business case evaluation. With the right conditions and implementation, LFG direct use not only improves the environment, but may provide cost savings to the bottom line by reducing expense with minimal capital investment.

Viable Landfill Sites

Identifying a viable site to begin the feasibility investigation begins with location. Since one of the major costs will be the interconnecting pipeline, a viable landfill for a direct use project needs to be within a reasonable proximity of the combustion equipment. Although unit costs for pipeline vary with terrain and surroundings (urban vs. rural), in general smaller projects of less than 500,000 MMBTU's per year will need to be within 5-10 miles of the landfill. This is just a rule of thumb as the real test is whatever distance that makes a positive business case for a project. Honeywell recently announced a project in Virginia that involves a 23 mile pipeline for over 3 million MMBTU's per year which establishes the new limit for LFG projects (Binker & Tonga 2005).

If the location of the landfill is within a reasonable distance to the direct use source, then the next critical selection criteria is the long term availability of landfill gas. Based on the capital investment, either by a developer or other entity, the project will need to provide an adequate return on investment to be considered by most industrial companies. Depending on the investment and investor, the length of commitment to purchase LFG will range from 10 to 20 years, typically, which means that the landfill will need to produce enough LFG during this period. Larger landfills that are regulated under EPA New Source Performance Standard (NSPS) are required to have collection wells and flares installed to destroy the methane collected. An NSPS landfill will usually have a history of LFG flared, records of waste collected, and projections for future waste and LFG generation that can provide an estimate of LFG generation with time. Of the many LFG prediction models, EPA's LandGEM is one of the easiest to use for high level estimation of LFG generation and can be used as a comparison to landfill reports (EPA 1999). Typically landfills will generate LFG for up to 40 years after waste has been placed in a landfill (Egolfopoulos, Qin &Tsotsis 2001). The range of LFG generation is dependent on many factors including type of waste, rainfall, cover of landfill, well placement… and thus is difficult to generalize; however, EPA has developed equations to estimate methane emissions from landfills with waste in place for 30 years as follows:

Estimate Methane Generation at Municipal Solid Waste Landfills

Small landfills (<2 MMT WIP): Methane (m3/min) = 7.43 WIP (10^6 MT)
Large landfills (> 2MMT WIP): Methane (m3/min) = 8.22 + 5.27 WIP (10^6 MT)
(Million Metric Tons= MMT; Waste in Place = WIP)
Source: EPA 2003a

Since landfills produce fairly consistent LFG year around due to the requirement to keep a constant negative pressure on the landfill, the lesser of the available LFG from the landfill or the base load from the combustion process being considered for LFG is the best estimate of LFG sales for analysis purposes. A landfill gas rights owner will want to maximize the sale of LFG so proposed projects that can use all of a landfill's gas generation will be preferred.

Facilities located within a reasonable distance to a landfill and that have combustion processes or heating loads equivalent to the supply from a landfill are good candidates to further evaluate the feasibility of developing a direct use LFG project.

Environmental Considerations

The environmental importance of the beneficial use of LFG is significant based on the reduction of methane to the atmosphere and use of renewable resources in-lieu of fossil fuels. The quantification of the reduction of methane is dependent on whether the landfill supplying the LFG for beneficial use is required by law to collect and control methane emissions. For example, in the United States (US), landfills classified as an NSPS site are required to collect and flare landfill gas. Therefore, a LFG beneficial use project at an NSPS landfill only provides an offset of fossil fuel use and not a reduction of methane to atmosphere. NSPS criteria for gas collection and flaring is required for landfills with design capacity exceeding 2.5 million mega-grams of waste or with emissions of non-methane organic compounds greater than 50 mega-grams per year (Hill & Rogoff 1996). Although only applicable to nations that have ratified the Kyoto Protocol, the United Nations Conference on Trade and Development has initiated a Clean Development Mechanism executive board (CDM) to develop and monitor Certified Emission Reductions (CERs). The applicability of landfill gas flaring, direct use, and LFG to energy to CERs is dependent on criteria that demonstrates that the beneficial use of LFG is not required by law and that the project would not otherwise be implemented based on return on investment (Eco Securities 2004). An example of an Emission Reduction (ER) calculation for a landfill gas to energy project is ER = (21 GWP of CH_4) * (CH_4 flared + CH_4 leacheate, if used + CH_4 electricity) in units of tones of CO_2 equivalent.

Another important environmental consideration is environmental permitting requirements. In the US a major modification of combustion equipment may require a "Permit to install" issued by EPA, State, or local agency as applicable. The agency will require the standard analysis of information, including demonstration that the combustion equipment has equal or better destruction efficiency of a flare. This has been satisfactorily demonstrated for boilers.

Quality of Landfill Gas

The required quality of LFG is dependent on the end use. The constituents of LFG vary by landfill, but are generally listed in Table 1. Methane is the most important constituent that provides the fuel source for beneficial use of LFG. Methane content varies by landfill design, waste content, age, and environmental conditions. Testing of the LFG for methane content is typically conducted if the LFG is required to be flared under NSPS in US and may be monitored under CDM rules for carbon credits. Testing should be conducted during various times of the year as rainfall and snowfall can affect methane levels. If there is not an active collection system installed at the landfill, then monitoring will be required with a pumping test from a gas recovery wells and monitoring probes that need to be installed (O'Leary & Walsh 2002). Methane content typically ranges from 45-60% with an average of 50% which results in energy content of about 500 (Btu/standard ft^3 of gas).

As the carbon portion of the carbon dioxide would have occurred naturally due to decomposition of the waste, the major concern for emitted CO_2 is the LFG effect on the combustion process. LFG combustion characteristics are different than natural gas, since the presence of CO_2 results in reduced flame temperatures and burning rates, a narrower range of flame stability, and thus lower combustion efficiency (Egolfopoulos, Qin &Tsotsis 2001). This variation must be accounted for in the design of burner modifications for the combustion of LFG.

Dependent on the end use of the combustion of LFG, other trace contaminants may be of importance. If the use is indirect heating, such as in a water-tube boiler, the trace contaminants are not material to the process as the only effect may be condensation of contaminants on the economizer tubes or other areas of the boiler. Refrigerant dryers followed by coalescing filters or desiccant dryers that dry to pressure dewpoints of 45 degrees Fahrenheit or lower can provide adequate condensation and filtration of vapors and liquids in LFG for boiler use. Dryers would typically be installed at the landfill to not only protect the end use equipment but the pipeline from contamination. General Motors has seven large landfill gas capable boilers in use, with some in operations for about ten years. Normal maintenance is adequate to monitor and clean any deposits on economizer tubes due to condensation of siloxane, which creates a silica type deposit. Other more critical uses in production processes may require additional drying or filtration to remove trace contaminants that may interfere with product quality or production processes.

A range of concentrations of trace organic compounds in LFG is shown in Table 2 from (3) different sources (Park, Park, Shin & Song 2001). Various mass transfer technologies are available for removal of these compounds. The most common removal technology is activated carbon, which is more effective when moisture is removed before treatment.

Siloxanes are another source of trace contaminants that may need to be removed prior to the use of LFG in combustion processes. Siloxanes are compounds used in household and commercial products that are disposed in landfills and volatize into LFG. During combustion, silicone dioxide is formed. Deposits on boiler pre-heater and economizer tubes are easily cleaned with routine maintenance; however, deposits on combustion turbine blades and other similar types of equipment can be problematic. The average rate of silica in LFG has been measured at 0.9 mg Si /MMBTU with an exponential decrease over time with age of waste (Pierce, 2005). Removal technologies include – Refrigeration followed by activated carbon, silica gel, or liquid scrubbing in packed towers. The most commonly used removal technology is activated carbon.

For large users of natural gas, blending of LFG with natural gas may be feasible without costly modifications to combustion equipment. Honeywell is using LFG for heat in a methane-steam hydrogen reformer at an ammonia manufacturing plant in Virginia. LFG is extracted from the landfill and pumped through refrigerant dryers and activated carbon to remove siloxane and piped 23 miles to the facility. LFG is combined with natural gas at a 15% rate to fuel the burners that provide heat for the reformer (Binker & Tonga 2005). If blending is not an option, then modifications to the combustion equipment will be necessary to directly use LFG in most natural gas burners.

Table 2. LFG Trace Contaminants

Toxic Trace Constituents	Range of Concentrations, ppm
Aromatics	
Benzene	0.0009 - 11.0
Toluene	0.05 - 163.2
Ethylbenzene	0.12 - 54.4
Xylene	0.05 - 88.2
Chlorinated Coumpounds	
Chloroform	0 - 183.9
Carbon tetrachloride	Non-detectable - 124.3
Trichloroethylene	0 - 58.1
Tetrachloroethylene	0 - 36.9
Sulfurs	
Hydrogen sulfide	0 - 427.5
Methyl mercaptane	0 - 84.9

Source: Park, Park, Shin & Song 2001

Equipment Modifications

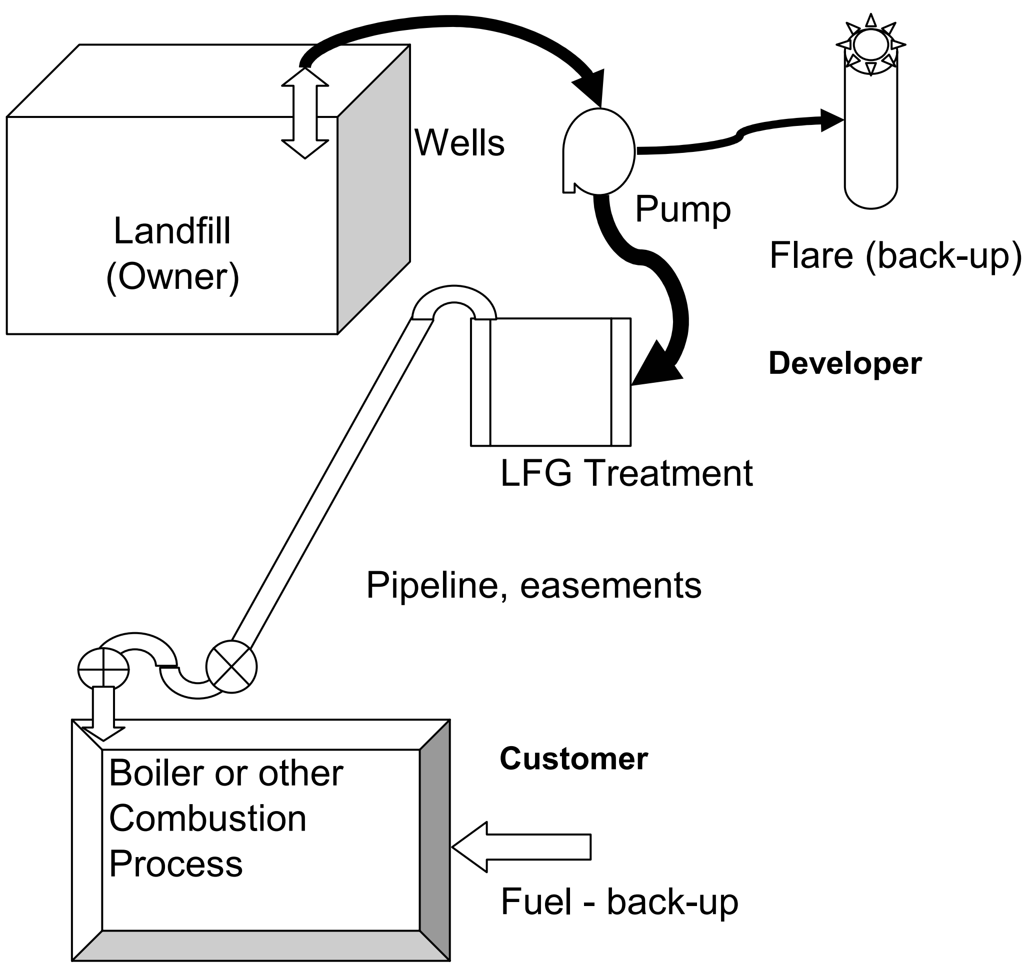
LFG direct use in boilers is most common, although other combustion processes can be similarly retrofitted to burn LFG in-lieu of or in combination with natural gas. There are a number of burner manufacturers that have experience with boiler conversion projects to allow LFG direct use. Other potential uses include any process that uses in-direct heating with combustion burners, thermal oxidizers, gas lances, and in-direct burners for heating. Processes that use direct injection of natural gas may be retrofitted easily to accommodate LFG, such as natural gas injection in regenerative thermal oxidizers.

EPA reports that over 70 companies have modified boilers to accommodate the direct use of LFG to displace fossil fuels. Since LFG has a different composition of methane and trace contaminants than natural gas, burner and boiler design modifications are required for effective use of LFG for combustion. Because LFG has about half of the energy content of natural gas the volume of gas through the fuel train and burner will be about twice that of natural gas requiring either a new burner and fuel train or modifications. Flame stability is important for reliable boiler operations. Due to the operating characteristics of landfills, LFG methane content and LFG supply may not be as reliable as needed to maintain flame stability and reliable steam or hot water output. Therefore, dual fuel capability with natural gas and LFG is usually recommended. This requires a burner retrofit that includes two fuel trains and burners for both natural gas, or other fuel, and LFG. Appropriate burner controls maintain igniters with reliable natural gas, use LFG as primary fuel, and provide back-up with natural gas through controlled use based on gas pressure available at the control valves respectively. The lower flame temperature of LFG may require modifications to the boiler super-heater, if applicable (EPA 2001). Trace contaminants may condense and cause corrosion concerns which can be corrected with proper selection of the materials of construction for the burner section, pre-heater, economizer, and stack.

Business Case Evaluation

An overview of the elements to consider in developing a business case to determine economic feasibility is shown schematically in Figure 1. The landfill owner typically owns the landfill gas rights or has assigned them to another party such as a developer. If installed, the LFG collection wells, pump or compressor, and flare may be owned and operated by the landfill owner, or subcontracted. Usually a developer or the landfill owner may be interested in constructing the treatment facilities, pipeline, and boiler or combustion device conversion. Knowledge of the provider of the services is essential to determine the cost portion of the cost and benefit analysis. For example, if the boiler or burner conversion is provided by a developer, then a reasonable return on investment will be included in the developer pricing.

Figure 1. Landfill Gas Direct Use Schematic



Landfill Gas Rights

Landfill Gas pricing from the owner of the landfill gas rights can either be market driven, if there is enough customer demand, or reasonably priced if only one customer exists. Market pricing could be established as a percentage of the replacement fuel, such as coal or natural gas indices. Regardless of the landfill gas owner's desire for pricing, in the end, the commodity price of landfill gas, when added to the remainder of the cost of service pricing, needs to be reasonable to the end user, providing enough benefit to enter into a long term agreement. A long term agreement is typically needed to provide a reasonable rate of return over time while providing an affordable price of LFG to the end customer. Historically, the value of LFG from the owner of the rights is in the 12% - 15% of the end price to the customer. This should provide enough revenue to a developer for return of the capital investment and cost of services.

Distribution Systems

The collection wells, compression system, and flare equipment may be pre-existing at the landfill and in operation due to regulatory or other reasons. Otherwise, the cost of installation will need to be factored into the capital recovery for either the landfill owner or developer. Also, the operating cost for energy, operations and maintenance needs to be included with the cost of services. The number, depth, and size of wells vary with each site; however, a recent project provided the following: 25 ft^3/min LFG per well at about one well per acre of landfill, $10,000 per well including interconnecting piping, $250/ ft^3/min LFG for filtration, condensation, and dehydration of LFG without trace contaminant removal, piping at $255,000 per mile of pipe with a mix of direct bury and directional boring and not including any easement purchases. These should only be used as preliminary estimates to determine if a project may be feasible since there are so many variables that influence cost.

Boiler Conversions

Boiler conversion costs vary with each system and are heavily dependent on the existing equipment age and condition of equipment. EPA reports that conversions on smaller boilers can cost several thousand to tens of thousands of dollars (EPA 2001). A recent project at General Motors involved a boiler conversion to burn LFG and natural gas for a 150,000 pound per hour, field erected, 245 psi, steam boiler that was over 20 years old. The cost was over $1M due to the boiler being originally designed for coal firing. A number of reputable equipment suppliers and contractors have experience in designing and building boiler conversions for LFG and dual fuel and can provide budgetary quotes for financial analysis.

Business Case Evaluation

Although each business will have a standard method of identifying a viable business opportunity, the basic cost benefit analysis using a discounted cash flow model should provide a high level identification of a positive business case. An informed customer with information on pricing for LFG can approach the market place with confidence to negotiate a fair and equitable price for LFG.

Assumptions (Small Landfill)

1. Landfill without any collection wells and 1.5 Million Metric Tons of Waste in Place

2. Landfill is 5 miles from a plant, in a rural area with a public right of way from the plant to the landfill. LFG is estimated at 500 btu/ft^3

3. The Plant's thermal energy use is 200,000 MMBTU/Year from Natural Gas use with (2) 50,000 Pounds per Hour water-tube package steam boilers with a process load base load of 25,000 Pounds per Hour of steam.

4. The landfill owner does not want to invest monies for a LFG project, but is willing to assign the gas rights.

Evaluation (Small Landfill)

1. Calculate the estimated landfill gas generated from EPA equation

   - 7.43 * 1.5 MMT = 11.15 m^3/min. = 395 ft^3/min.

2. Calculate the estimated use of energy from the base load of the boilers

   - 25000 pph * 1,000 btu/lb / 500 btu/ft^3 / 60 min/hr. = 833 ft^3/min.

3. The available landfill gas for use to offset fossil fuel is 395 ft^3/min or

   - 395 ft^3/min (cfm) * 60 min./hr. * 8760 hrs./yr. * 95% availability* 500 btu/ft^3 / $1x10^6$ btu/MMBTU = 98,616 MMBTU/Yr or about **100,000 MMBTU/Yr.** [1]

4. Estimate the cost for wells, distribution, and filtration, and piping to boilers

   - 395 cfm / 25 cfm / well = 16 Wells and distribution at $10,000 = $160,000
   - 395 cfm *2 (design) * $250/cfm = $197,500
   - 5 miles of piping without easement purchases * $255,000/mile = $1,275,000
   - Sub-Total estimate = $ 1,632,500

5. Estimate the cost to convert the package boiler from natural gas use to LFG

   - Estimate $100,000 to convert the burner and controls to efficiently use LFG

6. Estimate a developers price to implement the project and provide LFG

   - Add engineering and development cost to construction estimate at 30% or 1.35* $1,732,500 = $ 2,338,875

---

[1] This represents a conservative amount of LFG for preliminary evaluation; the system should be designed to accommodate the entire load available from the plant in case the amount available at the landfill increases.

- Assume a developer wants a 7 year simple payback or a revenue of \$ 2,338,875 / 7 = \$ 334,125 per year for a 10 year term
- Calculate the estimated price for landfill gas: \$334,125 / 100,000 = \$3.34 / MMBTU plus 15% for landfill owner = \$3.85 /MMBTU

7. Estimate the savings based on a 6 year historical gas price (DOE 2005) of \$5.68

- Conservatively the savings should provide about a positive cash flow of \$185,000 per year for 10 years and potentially beyond subject to the life expectancy of the landfill and landfill gas generation.

8. Calculate the un-levered Return on Investment if your company invested the capital

- Capital investment is \$ 2,338,875 and annual operating cost savings is (\$5.68 – 0.50) * 100,000 MMBTU = \$518,000 / year
- Using a standard corporate discounted cash flow calculation this project should provide an 18% return on investment based on 15 years or 14% based on 10 years of economic life.

9. Estimate the benefit to the environment

- CO_2 reduction from not burning natural gas = 117.65 lb / MMBTU * 100,000 MMBTU / Year = 11,765,000 lbs./year or 5,883 Tons / Year CO_2
- CO_2 equivalent from methane reduction due to non-NSPS site in US = 0.041 lbs./ft^3 * 395 ft^3/min * 21 GWP * 50% methane * 60 min./hr * 8760 hrs./yr * 0.95 availability / 2,000 lbs. / ton = 42,713 Tons / Year CO_2
- Total reduction of CO_2 to the atmosphere is 48,596 Tons / Year CO_2. With market trading of CO_2 Emission Reduction Credits, this could generate additional revenue for the project.

10. Summary

- If your corporate hurdle rate is between 14% and 18%, then this project provides a positive business case.
- If a landfill gas contract can be structured as a supply contract or operating lease, then the capital investment can be avoided and a positive cash flow \$185,000 / year which increases the net present value of the project by about \$1M over an owner's investment scenario.
- Almost 50,000 Tons / Year of CO_2 equivalent can be eliminated from the atmosphere.

Conclusion

Landfill Gas, if not properly combusted, is a significant source of man-made greenhouse gases. Although combustion of landfill gas in a flare reduces methane emissions to the environment, it is not the best end use of landfill gas if it can be combusted to displace the use of fossil fuels as a renewable energy source. There are approximately 380 operational LFG energy projects in the United States. In addition, about 120 projects are currently under construction or are exploring development options and opportunities (EPA 2005). End users can not only improve environmental conditions by using landfill gas in their processes, but they can improve their net income through reduced operating cost. The LFG project development process begins with evaluation of information about a candidate project to determine if it is technically and economically feasible. The quantification of the amount of LFG, the quality requirements, environmental considerations, process equipment modifications, and a preliminary business case evaluation are required to initially determine if a project is feasible. Although many companies have already been using landfill gas beneficially for over 10 years, the opportunity for others still exists. This opportunity needs to be pursued further to assist in reducing greenhouse gas emissions and increase the use of renewable energy with the potentially added economic benefit.

References

Brinker, B and K. Togna. 2005. *The Honeywell Project: Going Where No Pipeline Has Gone Before*. Available online: http://www.epa.gov/lmop/conf/8thconf.htm

Egolfopoulos, F, W. Qin, and T. Tsotsis. 2001. "Fundamental and environmental aspects of landfill gas utilization for power generation". Chemical Engineering Journal. (82) 157-172

[EPA] Environmental Protection Agency. 1999. *Landfill Gas Emissions Model, version 2.01*. Available online: http://www.epa.gov/ttn/catc/products.html

EPA. 2001. *Adapting Boilers to Utilize Landfill Gas: Feasible and Cost-Effective*. Available online: http://www.epa.gov/landfill/res/pdf/boilers.pdf

EPA. 2003. *Methane Human Related Sources*. Available online: http://www.epa.gov/methane/sources.html

EPA. 2003a. *Methane Sub-model for the US EPA Markal Model*. Available online: http://www.epa.gov/methane/pdfs/Methane_Sub-Model_Data_Report_Final.pdf

EPA. 2005. *Accomplishments.* Available online: http://www.epa.gov/lmop/accomplish.htm

Hill S. and M. Rogoff. 1996. "Zeroing inn on NSPS and EG for Landfill Gas." *Waste Age Magazine*. July1.

O'Leary P. and P. Walsh. 2002. *Landfill Gas Movement, Control, and Uses*. Available online: http://www.cepis.ops-oms.org/muwww/fulltext.html

Park J., K. Park, H. Shin, H. Song. 2001. "Removal characteristics of trace compounds of landfill gas by activated carbon adsorption." Environmental Pollution (119) 227-236.

Pierce J. 2005. Siloxane Removal Technologies. Available online: http://www.epa.gov/landfill/conf/8th/presentation/Pierce.pdf