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LANDFILL GAS ENERGY UTILIZATION: TECHNICAL AND NON-TECHNICAL CONSIDERATIONS

John G. Pacey
Chairman-SWANA's Landfill Gas Recovery and Utilization Committee
Emcon Associates

Michiel R.J. Doorn
E.H. Pechan & Associates, Inc.

Susan A. Thorneloe
Chairman-SWANA's Technology Development and Tracking Committee
U.S.EPA/Air and Energy Engineering Research Laboratory

ABSTRACT

Clean Air Act (CAA) regulations for new and existing municipal solid waste landfills, to be final in June 1994, are expected to require about 700 medium and larger sized sites to install and maintain a landfill gas (LFG) extraction and control facility to reduce greenhouse gas and nonmethane organic compound emissions. (U.S. EPA, 1991 and Najarian, 1994) The control system may be a flare or energy recovery through (1) use directly as medium heating value fuel, (2) generation of electricity using internal combustion engines, gas turbines, or fuel cells, or (3) upgrading the gas to pipeline quality or using it as vehicular fuel. For the majority of these landfills, this will result in a new layer of cost and management. The question many landfill owners and operators will ask is are there ways to minimize this cost and management by some form of energy conversion activity?

This paper summarizes ongoing research at EPA's Air and Energy Engineering Research Laboratory (AEERL) on LFG utilization. This paper provides a discussion of the technical issues associated with the use of LFG compared to those of natural gas -- which is the primary fuel used for energy conversion equipment such as internal combustion engines, gas turbines, and fuel cells. LFG is a medium heating value fuel containing trace constituents that require gas pretreatment and energy equipment modifications to operate successfully. Technical problems associated with energy equipment when used for LFG applications can result due to chlorinated and toxic compounds, particulate, and reduced heating value [18.6×10^6 vs. 37.2×10^6 joules/m^3 (500 vs. 1000 Btu/scf)]. There are over 100 LFG-to-energy projects in the U.S., and the developers and operators have found different ways of minimizing the potential problems associated with LFG utilization. The EPA/AEERL has ongoing research to understand the different philosophies of major developers and operators of U.S. projects along with data on European and Australian projects. This research is collecting data on non-technical issues such as project barriers and incentives, developing (1) a list of active LFG developers, (2) graphs showing the relationship between LFG delivery and energy output, and (3) insights on project decision making. This paper provides a brief overview of this research.

The research described is funded through the U.S. EPA's Global Climate Change Research Program. This research is part of a larger EPA research program to develop more reliable emission estimates for the major sources of greenhouse gas emissions. This research is being conducted in support of the goals established at the United Nations Conference on Environment and Development in 1992.

1. INTRODUCTION

The landfill owner/operators of the 700 sites that are estimated to be affected by the CAA regulations will be making decisions over the next several years about the type of system to control. It is expected that the rule to be published this summer will require sites containing a million tons of waste or more and that have a mass emission rate of 50 Mg of nonmethane organic compounds (NMOC) to install gas extraction and control systems (Najarian, 1994). Control systems may be categorized as follows:

- Flares.
- Energy recovery systems;
  - direct use as medium Btu fuel; e.g., in boilers and brick or cement kilns
  - generation of electricity using reciprocating internal combustion (IC) engines, gas turbines, or steam turbines, and
  - upgrading the gas to pipeline quality or using it as vehicular fuel.

AEERL has ongoing research to help provide information on energy conversion options for LFG utilization as a means of assisting those landfills impacted by these upcoming regulations. (Thorneloe, 1993 and 1994) This information will help in understanding and defining the different options available. The first report from this research was published in June 1992, provided an overview of the different options for LFG utilization, and identified the major capital and operating costs for the different options. (Augenstein and Pacey, 1992) The report provided data and information on over 50 projects with detailed case studies on six sites.

A follow-up project is currently in progress to develop additional information to assist in evaluating the technical and non-technical issues associated with these energy conversion options, and to assist in the decision making considerations. The core of this work is a series of very extensive interviews conducted with six companies involved in LFG utilization project development, operations, and/or management. Data have also been collected on European and Australian LFG-to-energy projects.

2. NON-TECHNICAL ISSUES AND TRENDS

Most of the sites required by the CAA regulations to install and maintain LFG combustion and control systems will have this requirement for at least 30 or more years. Many sites will transfer these costs through their disposal fees. Others may not have the time or ability to pass these costs through to the disposal generators and will have to look at other ways to minimize potential compliance costs. The soon-to-be-final CAA rules will require about 700 sites to collect and control the LFG through combustion. The landfill owner/operator may choose flaring or energy recovery. The choice of energy recovery may result in offsetting the cost of compliance. However, many of the projects in place today in the U.S. (110 projects currently) had, or have, special incentives which help make them economical. The energy prices in most of Canada and the U.S. are currently so low that new projects are discouraged, although a few are in the planning and construction phase. There is concern that, without encouragement of these projects through incentives and consideration of pollution prevention benefits, many of the sites affected by the CAA rule will choose to flare the gas rather than utilize it.

Non-technical issues include, but are not limited to: 1) energy conversion (i.e., direct gas use, electricity generation, upgrading gas to pipeline quality), 2) project economics (financing, return on investment, profit, cost/benefit, etc.), 3) barriers and incentives, and 4) organizational structure. (Thorneloe, 1992)

1) Energy conversion: This includes direct utilization in boilers, cement kilns, etc. to produce heat; as fuel for internal combustion engines and gas and steam turbines in

the production of electricity; and as a feedstock for producing high Btu quality gas for use as equivalent pipeline quality gas. These and other processes under development are discussed in detail in an EPA/AEERL report. (Augenstein and Pacey, 1992) Technical issues, remedies, and field experience associated with these processes are presented later in this paper. Figures 1 through 4 demonstrate the trend in number and type of energy conversion projects, major manufacturer's equipment selected for the electricity conversion projects (the principal energy conversion choice of the small to medium size landfills), and major developers. In general the direct firing options (e.g., boilers) are the least costly and most favored.

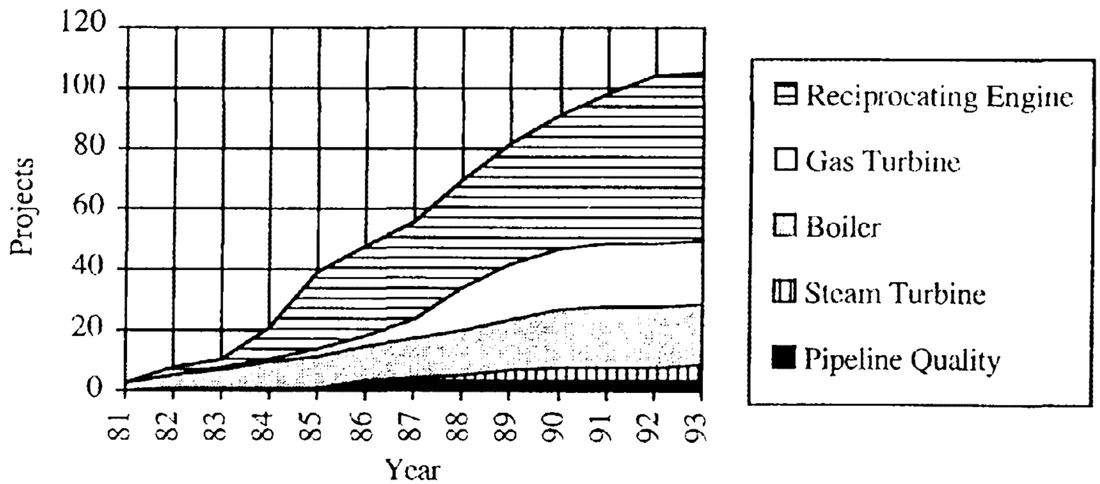

Figure 1. Number of projects per end use per year

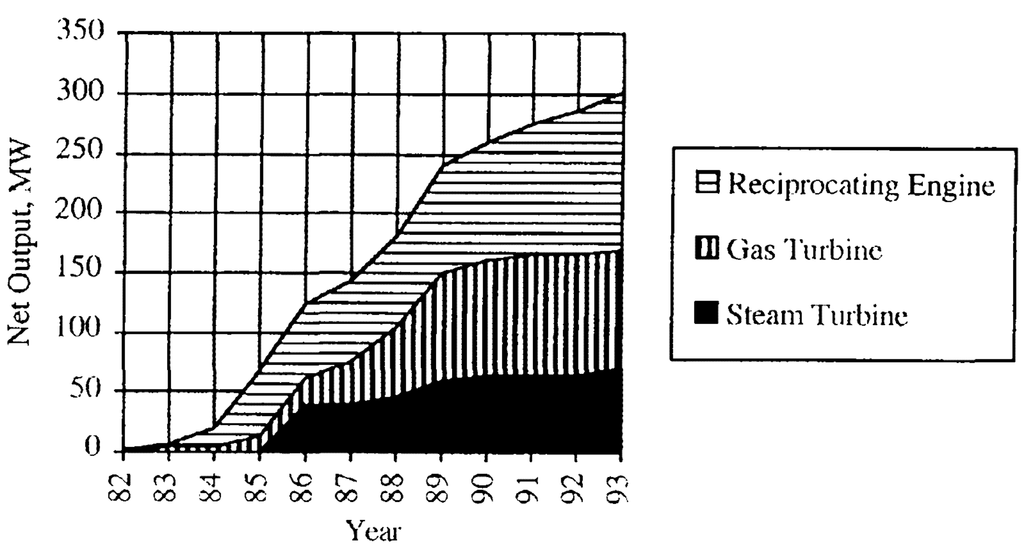

Figure 2. Net electrical output in MW per year per type of generating equipment

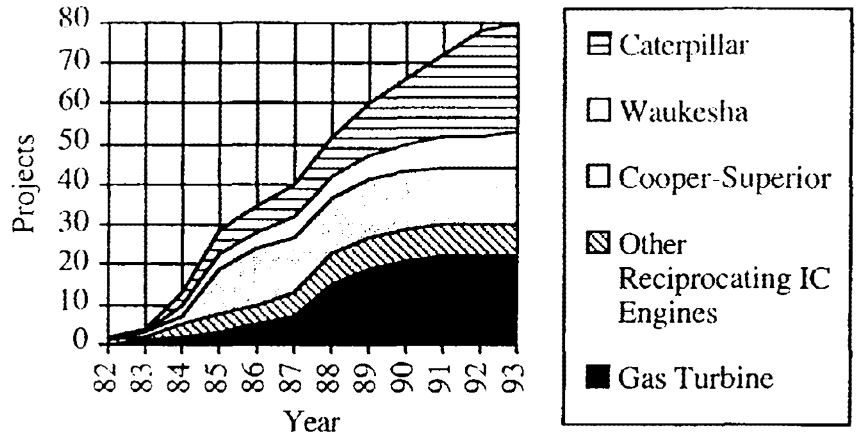

Figure 3. Number of IC engine projects (incl. gas turbines) per manufacturer per year

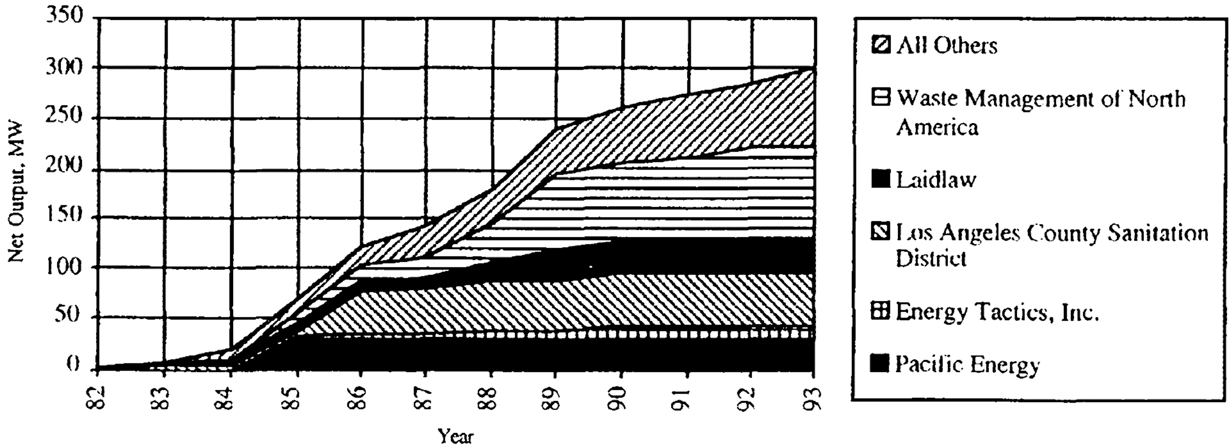

Figure 4. Net electrical output in MW per developer per year

2) Project economics: Project economics are seemingly straightforward; however, numerous economic barriers and incentives can impact LFG projects. A new point of view on project economics must address the prospect that, with low energy prices and numerous barriers to development of LFG projects, the owner/operator may become involved as a partner with a prospective LFG energy developer. The owner/operator may have to provide all, or a portion, of the costs and management associated with the extraction system, at least during the economic life of the energy conversion project. After this period, the owner/operator would be responsible for the cost of the gas extraction/control system.

Financing is frequently an issue with LFG project development. As always in a free market the lender wants security, and the developer wants profit. The lending rate is a function of many things, but risk is high on the list of concerns by today's financial institutions, and LFG projects receive close scrutiny with today's lenders. The LFG industry to date has not demonstrated a high success rate, evidenced by the few open market developers and their longevity in the industry. On occasion the manufacturer will assist in the project; utility company subsidiary companies have assisted in financing project development.

3) Barriers and incentives: The soon-to-be-final CAA regulations for new and existing municipal solid waste landfills will cause more LFG to be extracted from landfills and hence a significant reduction in LFG emissions. To realize the pollution prevention benefits resulting LFG utilization, it is hoped that the increase in LFG extraction will result in additional LFG-to-energy projects. This is being encouraged by recent steps taken by the federal government as called for by the President's Climate Change Action Plan (October 1993).

Factors that can discourage the development of new projects and the expansion of existing projects include:

- unfavorable economics due to low energy costs and high debt service rates for LFG-to-energy projects that generate electricity or pipeline quality gas,
- a limited and unstable market place,
- increased requirements for nitrogen oxide and carbon monoxide emissions for projects located in nonattainment regions as required by the CAA Amendments,
- difficulties in negotiating power contracts with local utilities who are primarily interested in purchasing low-cost power without considering environmental externalities (e.g., offsets from power plants using fossil fuel),
- taxation by some states, such as CA, on LFG extraction and energy conversion facilities, and
- federal and state energy policies and environmental regulations.

Energy costs have varied over time and are different across North America. This is because LFG has competitive energy forms and pricing, and the same energy form has its own pricing that varies widely according to geographic location. LFG has to compete with coal, oil, natural gas, etc. At present the value of most energy is too low for the LFG energy conversion price to be cost effective on its own.

For the most part, LFG users must be in close proximity to the landfill, as it is costly to install pipelines for transport offsite. This is what makes electricity production the most favored of LFG energy conversion projects: electricity distribution lines are usually in reasonable proximity to the landfill. The LFG user should be a stable company, and the pricing structure should be reasonably stable and sufficient to support project economics. Utility companies find high favor in this regard for longevity of contract. Energy price swings have seriously impacted LFG project impacts when they remain in the lows of the past decade.

Many of the developers who were interviewed reported difficulties in the planning process, interaction with state and local air agencies, and a variety of state and federal regulations. Often permits must be obtained from several different agencies including permits for safety, solid waste, water, and air. Industry has claimed that often the rules are conflicting and that pollution prevention benefits are not considered. (Wong, 1992)

Factors to consider that help to encourage projects in the U.S. include:
1) Production Tax Credits (PTCs); 2) favorable utility contracts for electricity projects; and 3) tax exemptions for LFG extraction and energy conversion facilities.

PTCs are available to a tax paying entity that has the right to sell the LFG and does sell it to an energy user who purchases the LFG and converts it to energy. Some states require that utilities pay incentive rates to LFG projects and may mandate that a certain level of capacity be derived from LFG projects. Some states exclude the LFG-related energy conversion systems from state taxation. Some utilities are encouraging LFG energy conversion projects by participating in their development. Some states are joining in ventures to encourage LFG development. It is important to investigate state and utility interests and goals, insofar as LFG energy conversion projects are concerned.

4) Organizational structure: There are many variations in the position the owner/operator takes in regard to development of an energy conversion project on a site. It is important to recognize that successful energy recovery projects appear to embody the following key elements:

- they are run by experienced professional management,
- they are adequately financed so that labor, inventory, and supplies are on hand as needed,
- they have an excess LFG gas supply and a favorable market place,
- the landfill is active and remains so for 5 to 10 more years,
- contracts for the gas rights, power, or gas sales and facility use are solid and of proper term, and
- the project should have experienced personnel and backup for servicing of the LFG extraction and energy conversion systems.

Nowadays, some companies provide turnkey design/construction for energy conversion units and will provide the operating and maintenance (O&M) activity as well; some provide the same turnkey service for the extraction systems. While the service industry is not big, it is adequate and growing to service the needs associated with the CAA.

3. TECHNICAL ISSUES

3.1 Chemical and Physical Condition of LFG

LFG is dirty and wet: moisture in LFG is acidic and corrosive. LFG trace gases are primarily NMOCs, mostly from volatile materials discarded in refuse. Most NMOCs are harmless in energy uses, but potential problems are caused by halocarbons, including the chlorofluorocarbons widely used in the past in refrigeration equipment and as aerosol propellants, and other solvents such as dry cleaning fluids. By-products from the combustion of halocarbons are readily reactive with, for example, metal in internal combustion (IC) engines. Other NMOCs (such as organic acids) can also present corrosion problems.

3.2 Particulate Matter and Deposits

Landfills contain soil and other particulate material which can be drawn into the LFG stream. This poses various problems, including deposits in IC engines and buildups in the oil of IC engines resulting in shortened oil life and increased wear. Particulates can be removed by gas filtration, but dimethyl siloxane deposits may still slowly build up in IC engine cylinders or in gas turbines and are effectively averted by gas refrigeration. Siloxane deposits may have the following severe consequences:

- Over time they slowly decrease combustion chamber volume, and increase compression ratio and tendency to detonate.
- Chips of deposited material may flake off and cause abrasion of parts such as valve stems and guides.
- Finally, the deposits are typically hard, so that removal requires power tools.

3.3 LFG Energy Content

Compared to natural gas, nonmethane constituents dilute the LFG, reducing its energy content per unit volume. One consequent requirement is that the energy system, including valves, pipes, and fuel metering, must introduce about twice the gas volume, relative to incoming air, as is required with pipeline gas. LFG displays temporal variations in volume and energy content. Gas energy content must be known and monitored so that fuel metering (for example the air/fuel ratio) can be adjusted. Gas composition may be measured by methods based on principles of thermal conductivity, infrared absorption, or gas chromatography. Flow is typically measured by Pitot tube, orifice plate, and turbine flowmeter methods.

4. TECHNICAL REMEDIES

4.1 Material Modifications

- For gas pretreatment, one simple rule is to prevent condensate as much as possible and to avoid carbon steel where an aqueous phase might occur. When used in low pressure situations [i.e., less than 70×10^3 pascals (10 psi)], carbon steel users may coat the steel with corrosion-resistant plastic or use polyvinyl chloride (PVC) and polyethylene. For higher pressure applications, zinc- or epoxy-coated carbon steel or stainless steel may be used. Alternatively, with polyethylene pipe and where cleanliness is not an issue, traps may be used. A case study has been reported. (Augenstein and Pacey, 1992)

- For energy conversion equipment, material adaptations are most prevalent with reciprocating IC engines. The parts of engines most frequently susceptible to corrosion or wear have proven to be exhaust valves, valve guides, and stems. In many cases these are now chrome plated. Based on reports from those surveyed, including both operators and manufacturers, modifications do not appear to be extensive and are nowadays custom built into engine models that are standard for natural gas.

- Turbine and boiler manufacturers indicate that typically no significant material modifications are made to the "standard" for conventional fuels applications.

4.2 Condensate Management

Condensate is the dilute solution (1 to a few percent) of the condensed water and contaminants found in LFG that may form as a result of decreasing gas temperature, and/or increasing pressure. Condensate generated in field collection lines must be drained to avoid blockage. Even with appropriate field collection system drainage, some condensate will typically reach the plant. Further condensate can also result within the plant, due to cooling or refrigeration following gas compression.

To manage condensate in the field, gas pipes and headers are sloped to allow drainage to a low point, where the liquid is collected in condensate traps. To protect the motor, blower, or compressor unit from a large billow, a condensate interceptor tank [3,785 liters (1,000 gallons) or larger] is usually placed directly ahead of the blower or compressor.

Depending on the choice of energy conversion equipment, the LFG may be compressed to low or high pressure. Management may elect to slightly cool the gas, refrigerate it to slightly above freezing, or cool it to minus 30 or 35°C (minus 20 or 30°F). Compression (with aftercooling), refrigeration, and cooling to minus 30 or 35°C (20 or 30°F) can generate progressively large amounts of condensate as the gas loses its capacity to hold water and other condensibles (which is the intention). With IC engines, evidence suggests that condensate may produce deposits and accelerated wear in IC engines, which may be due not only to deposits but also to the corrosive nature of condensate.

Another approach to condensate management is to avoid its formation. For instance, after passage through the knockout tank, the gas may be reheated to avoid further condensation in the gas feed lines prior to the engines. This may be done in an air exchanger where heat from the gas leaving the blower is absorbed. Refrigerating the incoming gas stream and removing the resulting condensate has been observed to result in some benefits (reduced engine deposits, increased oil life, and reported reductions of other problems). Refrigeration is most widely applied with IC engines.

To remove water vapor, a chemical desiccant, such as glycol or silica, may be used. Several more rigorous cleanup methods may also be applied to remove stubborn contaminants.

4.3 Oil Selection and Management (Reciprocating IC Engines)

With conventional fuels, corrosive compounds stem largely from combustion of the sulfur in the fuel. However, for LFG-fueled reciprocating IC engines, the compounds of concern are the halogens which contribute to an acidic environment. Chemical additives to the oil can largely neutralize these compounds and reduce corrosion of engine metal that would otherwise occur. Because of the severity of oil service in LFG engines, frequent oil analyses are conducted in which Total Base Number, nitration, metal content, and various other components are followed to determine when replacement is warranted. Levels of metal concentrations will indicate the degree of wear since the previous oil change, and can help to detect engine problems.

The buildup of deleterious volatile compounds in engine oil may be reduced by providing positive crankcase ventilation. Another route to reduce buildup of volatiles in the oil is to increase cooling water temperature, hence block and oil temperature, so that evaporation is maximized and condensation minimized. This will also facilitate vaporization of water in the oil. Ongoing research by EPA/AEERL has developed a case study on lubrication of spark ignition engines at the Stewartby site in the United Kingdom.

4.4 Engine Adjustments (Reciprocating IC Engines)

On average, LFG contains only half the amount of methane that natural gas has, necessitating modification of the fuel/air ratio for gas engines originally designed for natural gas. Controls are recommended to maintain the desired fuel/air ratio at a relatively constant level, as energy content of the incoming LFG may vary. Detailed information on approaches to carburetion with LFG-fueled reciprocating IC engines has been collected by EPA/AEERL and is expected to be published later this year.

Proper spark advance for the mixture and conditions is key to efficient engine operation. A typical practice with reciprocating IC engines for natural gas, is to advance the spark to a constant setting or to follow a preset ratio. Sometimes the spark setting is adjusted, based on fuel/air composition which requires appropriate measurement and feedback. Maximum engine efficiency, whatever the fuel composition, is normally obtained with maximum advance (as long as detonation is avoided).

A general control problem in "lean-burn" reciprocating IC engines, that relates to both carburetion and ignition timing, is that sudden "fuel-rich" conditions may occur with swings in LFG energy content. This condition can result in detonation and severe engine damage. The air supply to lean-burn engines must be pressurized, by turbocharging. The expansion section is susceptible to damage from any deposits associated with LFG use.

5. FIELD EXPERIENCE

5.1 Boilers

The most common approach to gas cleanup is to apply minimum gas cleanup, limited to condensate knockout and optional filtration. Design adjustment needs to be made for the lower energy content of the LFG flow; an approximate doubling of burner orifice area (at constant fuel delivery pressure). When methane content in LFG varies widely, the maintenance of a constant volumetric flow ratio of LFG to air is an unsatisfactory control method. Also, if LFG composition changes rapidly, oxygen measurement and control may be too slow. Particularly for larger boiler systems, feed forward control (measuring methane or heat content) is then recommended. On the whole, the trim systems, which adjust fuel/air ratios based on oxygen sensed in the exhaust, seem to work well.

A LFG-fueled steam boiler, that supplies 53,000 kg/hr (24,000 lb/hr) (at peak output) of steam to a pharmaceutical plant in Raleigh, NC, is described in the first EPA/AEERL report on LFG utilization. (Augenstein and Pacey, 1992) Minimal gas cleanup is employed (condensate simply drops out of a low point in the 1210 meter (3/4-mile) gas pipeline supplying the plant). The boiler is equipped for multifuel operation, incorporating a LFG burner ring and separate dedicated oil and pipeline gas burners. No operating problems, related to LFG use, have been observed, and this boiler has functioned well to date. Some corrosion of the inner door and external pipe fittings did occur, but replacement cost is relatively low.

5.2 Reciprocating IC Engines

Early in the history of LFG energy (mid-1980s), cleanup of LFG for use in reciprocating IC engines was often limited to condensate knockout. This procedure was reported to be fairly inefficient: some condensate was actually aspirated into the engine with the LFG fuel, giving (as might be expected) poor results. Engines were stated to be "corroded out within a few thousand hours." A variety of design and materials modifications were applied to ameliorate problems. These included chromed valves and hardened piston rings. However, in one case, operating experience improved only when refrigerated gas cleanup was applied. Minimal cleanup regimens may suffice under certain conditions. This is the case at the Marina Landfill in Monterey County, CA. which uses no gas cleanup other than collection of condensate and minimal filtration (section 5.3 of Augenstein and Pacey, 1992).

Ongoing research at EPA/Air and Energy Engineering Research Laboratory is collecting data on operating practices and field experience. An example of the kind of information that is being obtained is included below. A major operator has recently published details of its experience and has provided further information in response to the survey conducted by EPA/AEERL. (Anderson, 1993) This operator uses lean-burn Caterpillar 3516 IC engines, and the gas processing sequence is:

- Knockout tank with top-end mesh pad,
- Gas supply [~$7x10^3$ to $50x10^3$ pascals (~1 to 7 psi)] to low-pressure engines with positive displacement Roots,
- Gas cooling to design dewpoint,
- Fine filtration and condensate removal, and
- Gas reheat to ~70°C (~20°F) above dewpoint.

On-line time has been between 89 and 95%. Under circumstances where gas availability is not limiting, 96% on-line time is even better. Top-end overhaul intervals are of the order of 8,000 hours, which matches Caterpillar's recommended interval. Oil changes are reported typically at 700 hour intervals.

5.3 Gas Turbines

Currently, five operators use LFG in turbines, mostly Solar Saturn or Centaur turbines. These are predominantly "standard" units, except that the combustors are modified to permit necessary entrance of more gas. There are no materials modifications to the turbines that are used, compared to their operation on pipeline gas. For all turbines, temperature control ("temperature topping") is necessary to prevent overheating of the blades and to maximize power recovery. For LFG-fueled turbines, where energy content may on occasion vary rapidly, the fuel/air control must react rapidly or temperature will overshoot. The temperature overshoot will "trip" and automatically shut down the turbine. To prevent this--which is more an aggravation, than a serious problem--the turbine is operated at a slightly lower temperature setpoint and efficiency than normal with conventional fuels.

A typical cleanup sequence would be:

- Knockout tank,
- Stainless steel wire mesh pad, or coalescing filter,
- LFG compression to $1.2x10^6$ pascals (175 psig),
- Separation of oil from compressed gas,
- Gas cooling by air heat exchange,
- Condensate removal by filtration,
- Reheat, and
- Final filtration.

5.4 LFG Purification to Natural Gas (Pipeline) Quality

The Environmental/Energy Division of Air Products and Chemicals, Inc. is the principal entity in pipeline gas preparation (although Browning-Ferris Industries also has a plant). The Gemini™ process used by Air Products, in very brief overview, consists of:

- Refrigeration to remove condensate,
- A solid sorbent pretreatment system employing activated carbon, iron sponge and other sorbents to take out the contaminants other than carbon dioxide (CO_2).
- Pressure-swing absorption CO_2 removal.

For both pretreatment and CO_2 removal, multiple fixed-bed columns are used and regenerated in a batchwise-continuous fashion (gas is cleaned up by columns with fresh sorbent, while other columns are regenerated off-line). Plant personnel consider this process to have performed satisfactorily. A general consideration with the above pipeline purification processes is that nitrogen and oxygen must be limited in the LFG to the plant, since none of the processes listed above can remove them.

6. DEVELOPING TECHNOLOGIES

6.1 Vehicular Fuel

Vehicle fueling with compressed gas is of high interest for environmental and other reasons. Technology for such fueling is well established. It was reported that, worldwide in 1990, at least 700,000 vehicles, including many passenger cars, were fueled by natural gas. Using LFG would involve purification and compression for reduced-volume storage on board vehicles. The vehicles would have to be equipped with conversion kits, which include safety devices, to manage the high pressures involved.

The Selexol Process and Pressure Swing Adsorption are two technologies with merit for the LFG industry. Both have been applied to projects with relatively large gas flows of 85 million liters (or 3 million standard cubic feet) per day or more. For smaller projects, membrane separation appears to be more suited. Membrane separation may be combined with absorption or other mechanisms. At the Puente Hills landfill of the Los Angeles County Sanitation District, a membrane separation system and a LFG fueling facility have been installed. A demonstration project is underway to verify the operational performance of different vehicles running on LFG that has approximately 97% methane. Ongoing research by EPA/AEERL is collecting data on emerging technologies for LFG utilization, and data are being collected on the LFG vehicle fuel experience from Puente Hills and other projects.

Other emerging technologies for LFG include the production of liquid diesel fuel such as in Pueblo, CO, that began operation last year. A second site in the U.S. has been proposed to produce vehicular fuel from LFG. The South Coast Air Quality Management District has awarded a contract to demonstrate a process for producing methanol from LFG. The site selected for this demonstration is the BKK landfill, where there was co-disposal of hazardous and municipal waste. This demonstration, scheduled to begin the summer of 1994, is to be conducted for 1 year.

6.2 Fuel Cells

Fuel cells have been a well established technology for generating energy for more than 20 years using natural gas. They are currently being considered for LFG applications. The EPA initiated a research, development, and demonstration (RD&D) project in 1991 to evaluate the use of commercially available fuel cells for LFG applications because of potential environmental and energy efficiency characteristics which include:

- higher energy efficiency (~40%) than conventional technologies,
- minimal by-product emissions which can be a critical consideration in nitrogen oxides and carbon monoxide nonattainment regions,
- ability to operate in remote areas,
- minimal labor and maintenance,
- minimal noise impact (i.e., there are no moving parts), and
- availability to smaller as well as larger landfills (available in 200 kW modules).

The major technical issue associated with the application of fuel cells to LFG projects is the gas cleanup system. Testing of the proposed system has just been completed, resulting in over 200 hours of successful operation at the landfill site where a 1-year demonstration is to occur. The gas cleanup system is designed to clean the gas to 3 ppmv of chlorides and 3 ppmv of sulfur. The 1-year demonstration will begin in the next few months, documenting the performance of fuel cells for LFG applications. (Sandelli, 1992)

The major non-technical issue associated with fuel cells has been capital cost. The manufacturer of the phosphoric acid fuel cell, International Fuel Cells subsidiary ONSI, has guaranteed to potential buyers that the capital cost for the new advanced power module will be $3000/kW for delivery in 1995. The manufacturer also has plans to reduce the cost to $1500 per kW by 1998. This will result in making the fuel cell competitive with conventional technologies in use today.

7. SUMMARY

This paper describes EPA/AEERL's current research to develop information to assist decision makers in evaluating the technical and non-technical issues associated with LFG energy conversion options. The core of this work is a series of extensive interviews conducted with six companies involved in LFG utilization project development, operations, and/or management.

The paper assesses current LFG utilization in the U.S. It describes possible obstacles LFG projects might face in the field, and practical solutions to such issues: material modifications, condensate management, oil selection, etc. A short overview of alternative LFG utilization options, such as conversion to vehicle fuel and utilization in fuel cells, is included.
The research described in this paper is funded through the EPA Office of Research and Development's engineering research program on Global Climate Change.

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16. ABSTRACT The paper discusses technical issues associated with the use of landfill gas (LFG) compared with natural gas--which is the primary fuel used for energy conversion equipment such as internal combustion engines, gas turbines, and fuel cells. LFG is a medium-heating-value fuel containing trace constituents that require gas pretreatment and energy equipment modifications to operate successfully. Technical problems associated with energy equipment when used for LFG applications can result due to chlorinated and toxic compounds, particulate, and reduced heating value (about 500 vs 1000 Btu/scf). There are more than 100 LFG-to-energy projects in the U.S., and their developers and operators have found different ways to minimize the potential problems associated with LFG utilization. The paper also gives an overview of developers and operators of these projects, data on European projects, non-technical issues such as project barriers and incentives, the relationship between LFG delivery and energy output, active landfill gas developers, and insights on project decision making.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Earth Fills	Stationary Sources	13C
Energy	Landfill-Gas-To-Energy	14G
Methane	Projects	07C
Natural Gas		21D

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