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TECHNICAL AND NONTECHNICAL ISSUES REGARDING LANDFILL GAS TO ENERGY - WHAT IS THEIR IMPACT ON THE U.S. LANDFILL GAS INDUSTRY?

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ABSTRACT

The U.S. landfill gas (LFG) industry is a relatively new industry with just over 20 years of experience. Many changes have occurred to this industry which are summarized in this paper. In addition, to responding to technical and nontechnical issues in the development and operation of LFG to energy projects, the industry will be responding to new regulatory requirements for LFG emissions. Clean Air Act (CAA) regulations for new and existing municipal solid waste (MSW) landfills which were proposed in May 1991 are scheduled to be promulgated in August 1995. These regulations are expected to require up to 400 landfills to install and maintain a LFG extraction and control facility to reduce landfill air emissions. These emissions include nonmethane organic compounds (NMOCs) which contribute to tropospheric ozone, methane which is a potent greenhouse gas, and toxic compounds which are of concern to public health. (U.S. EPA, 1991 and Najarian, 1994 and 1995) In addition, landfills that are subject to New Source Review may also be considered for controls to reduce landfill air emissions. Control options include flaring the gas or combustion with energy recovery which includes (1) direct use of the gas as medium heating value fuel, (2) generation of electricity using reciprocating engines, gas or steam turbines, or fuel cells, or (3) upgrading the gas to pipeline quality or to produce vehicular fuel. Many landfill owners will be evaluating their options for controlling landfill air emissions and will be considering if it is practical and economical to minimize potential control costs through the development of a LFG utilization project.

This paper summarizes ongoing research at EPA's Air Pollution Prevention and Control Division (APPCD), the former Air and Energy Engineering Research Laboratory, on LFG utilization. Research was conducted to identify the technical issues and solutions through interviews conducted with industry experts in the U.S., Europe, and Australia. The U.S. developers and operators who were interviewed represent over 70% of all the projects in the U.S. Technical issues associated with the use of LFG as compared to natural gas -- which is the primary fuel used for energy conversion equipment such as internal combustion engines, gas turbines, and fuel cells -- can result due to chlorinated and toxic compounds, particulate, and reduced heating value when compared to natural gas [18.6×10^6 vs. 37.2×10^6 joules/m^3 (500 vs. 1000 Btu/scf)]. A recent database of LFG to energy projects that has been developed through a collaborative program between EPA/APPCD and the Solid Waste Association of North America (SWANA), indicates that, as of December 1994, there were 137 LFG-to-energy projects in the U.S. and 9 in Canada. This paper will provide summary statistics and industry trends resulting from this database, and a

discussion of the nontechnical and technical issues and "solutions." Other EPA/APPCD research that will be discussed in this paper is a recent overview of emerging technologies for LFG utilization and research regarding the demonstration of fuel cells for LFG utilization.

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 and to identify cost-effective opportunities for reducing 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 and the Climate Change Action Plan (President Clinton and Vice President Gore, 1993).

INTRODUCTION

The EPA/APPCD has estimated that U.S. landfills containing municipal solid waste (MSW), industrial waste, and construction and demolition debris waste contribute 9 to 18 teragrams (Tg) per year of methane with an average of 13 Tg (Doorn, Stefanski, and Barlaz, 1994). Global methane emissions from landfills and open dumps have been estimated by EPA/APPCD to range from 19 to 40 Tg/yr with an average of 30 Tg/yr (Doorn and Barlaz, 1995). Global anthropogenic sources emit 360 Tg/yr (IPCC, 1992), which suggests that landfills and open dumps account for 5 to 11% of the total (Thorneloe, 1993). Soon-to-be-promulgated CAA regulations are estimated to result in a reduction of 5 Tg/yr of methane or 39% of the baseline emissions attributed to MSW landfills. Many other countries are also looking at regulatory controls or incentives to encourage control of LFG emissions as part of the goals set in 1992 to stabilize greenhouse gas (GHG) emissions to 1990 levels by the year 2000. EPA/APPCD is conducting research to: (1) develop more reliable estimates of landfill emissions including methane and NMOCs, (2) develop emission methodologies for estimating landfill emissions, (3) evaluate existing and innovative and/or emerging technologies for LFG pretreatment and utilization, (4) develop technology transfer information to assist landfill owner/operators who are considering control options, and (5) demonstrate innovative technologies for LFG such as the use of fuel cells. In addition, APPCD and SWANA have developed a more reliable database of LFG-to-energy projects in North America (Thorneloe and Pacey, 1994). This paper provides a brief summary of this research.

The EPA's Office of Air Quality Planning and Standards has estimated that 400 landfills will be affected by CAA regulations that are scheduled for promulgation in August 1995. These rules include New Source Performance Standards and Emission Guidelines that will require landfill owner/operators to install LFG extraction and control systems over the next 2 to 5 years. Landfills that are anticipated to be targeted by the rule are those sites that contain 2.5 million tons (2.25 million tonnes) of waste or more and that have a mass emission rate of 50 Mg/yr of NMOCs (Najarian, 1995). Control systems may be flares or may include energy conversion such as:

- Direct use as medium heat-value 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 for use as pipeline quality gas or as vehicular fuel.

A LFG-to-energy project provides an opportunity to offset potential control costs, but many factors need to be considered in determining if it is practical or economical. In addition, many factors need to be considered when designing and operating these systems.

APPCD interviewed major developers and operators to gain insight into the philosophies that lead to successful projects. The findings from this research were recently published (Doorn, Pacey, and Augenstein, 1995) and indicate that there are a variety of views with varying trade-offs regarding issues such as the extent of gas cleanup and frequency of energy-equipment overhauls. This report was a follow-up to research conducted in 1991 and 1992 which reviewed the state of technology of LFG applications, provided detailed case studies of 6 sites and information on over 50 projects, and reviewed the major capital and operating costs (Augenstein and Pacey, 1992, Thorneloe, 1994). In addition, information on the nontechnical barriers has also been documented through interviews conducted with industry and regulatory experts (Thorneloe, 1992a and Doorn, Pacey, and Augenstein, 1995). Recently completed research included a review of emerging technologies including up-to-date information on fuel cell technology and processes for producing methanol from landfill gas. A series of technical reports have been developed which are summarized in this paper. This information is to help those who are making decisions regarding whether to develop a LFG-to-energy project.

NONTECHNICAL ISSUES AND TRENDS

The U.S. LFG industry is 21 years old. The first commercial LFG energy conversion project was initiated in 1974 and was placed on-line at Palos Verdes landfill, Rolling Hills, California, in 1975. It converted LFG to pipeline quality gas that was sold to the Southern California Gas Company. Several additional LFG-to-pipeline-quality projects were brought on-line in the late 1970s, including Mountain View (1978) and Monterey Park (1979), both in California. Direct-firing-boiler projects were brought on-line in the late 1970s and early 1980s. The first LFG-to-electricity project occurred at Brattleboro, Vermont, in 1982, and electrical projects have dominated ever since. Currently there are 137 LFG utilization projects in the U.S. and 9 in Canada. Most projects are in California and the Northeast.

In general, we found that most developers utilize incentives that help to overcome unfavorable economics which are primarily due to low fossil fuel cost. Over the last decade, energy prices have neither been adequate nor sufficiently stable to support new projects. States that have provided incentives have helped to encourage new projects. For example, in 1984 California offered what is known as Standard Offer #4 (i.e., SO_4) which provided a price favored contract that utilities must offer. The last project under SO_4 was started in 1990. Several of these contracts have expired, and some projects have had to close down when the pricing structure reverted to the avoided cost price basis (of the utility). New Jersey, New York, and Pennsylvania adopted a Pioneer Floor Rate of $0.06 per kilowatt-hour (kWh) in the mid-1980s; however, this was canceled several years ago. Illinois, Michigan, and Wisconsin have offered energy price incentives to limited LFG projects, thereby encouraging project development. In the recently completed report (Doorn, Pacey, and Augenstein, 1995), figures are provided showing the distribution of projects in the U.S. and the number of projects by state, electrical output, and the type of generating equipment. As a result of the potential CAA regulations requiring 400 sites to install LFG extraction and control systems and efforts by EPA's Outreach Program to encourage states and utilities to encourage LFG utilization, an increase in the number of new projects is expected.

Nontechnical issues also exist in other countries, and a recent paper by the International Energy Agency indicated that for projects to be successful there needs to be a recognition of the potential for LFG-to-energy utilization and the environmental benefits resulting from these projects which include the conservation of fossil fuel (Meadows and Maunder, 1995). Nontechnical 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, 1992b). These issues are discussed below.

Energy conversion: Generally, direct firing (i.e., boiler or kiln), immediately adjacent to the landfill, is the most cost effective type of project. However, boilers are not always near landfills with continuous fuel demands (i.e., 24 hours a day, 7 days a week). Also, larger landfills produce quantities of gas that require several nearby gas customers requiring continuous demand for fuel in order for all of the gas to be utilized. In the U.S., 33 projects out of 137 (i.e., 24%) are direct gas use. Reciprocating IC engines are the most widely used option with 73 projects or 53% of the LFG-to-energy projects in the U.S. The recent trend towards the use of low-pressure engines eliminates the need for high pressure compressors which reduces by-product emissions and parasitic loading. Projects that upgrade gas to pipeline quality have not been economically viable over the past decade although there is an interest in vehicle fuel projects. The major trend of the last decade has been significant growth in the use of reciprocating IC engines for LFG-to- energy applications (Figure 1).

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.

Figure 1. Number of projects by end use and year

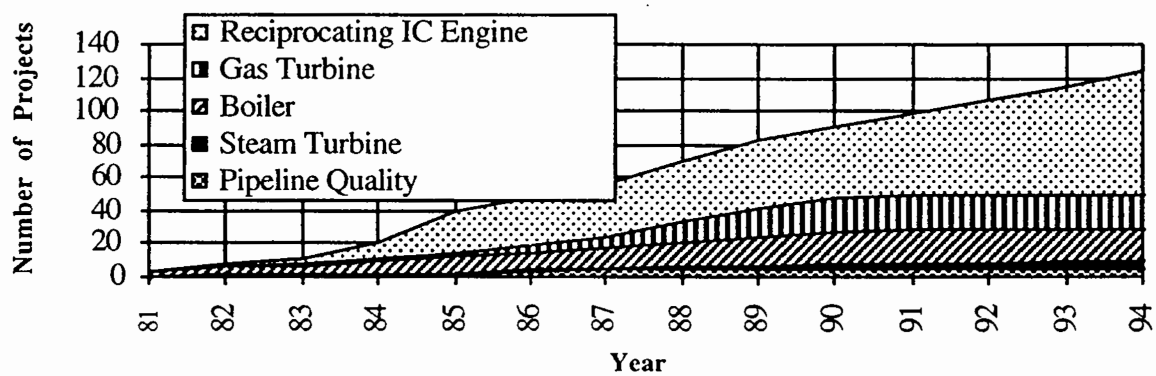


Figure 2. Net electrical output in MW by year and type of generating equipment

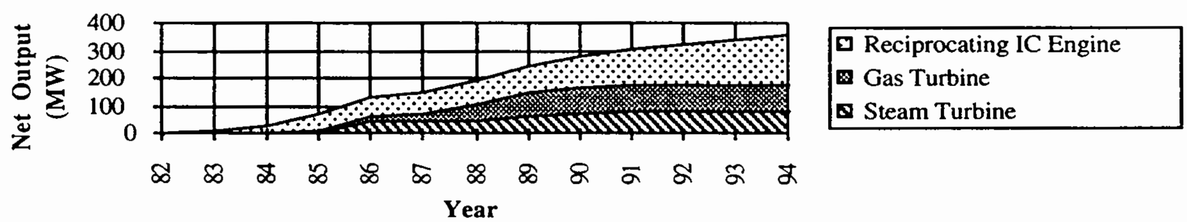


Figure 3. Number of IC engine and gas turbine projects by manufacturer and year

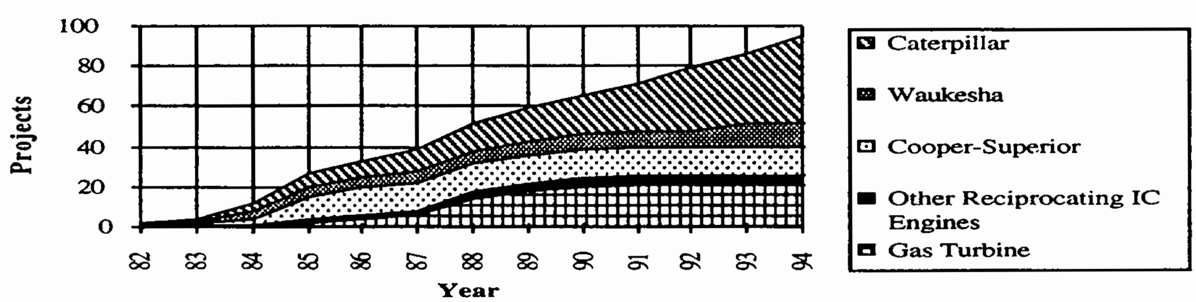
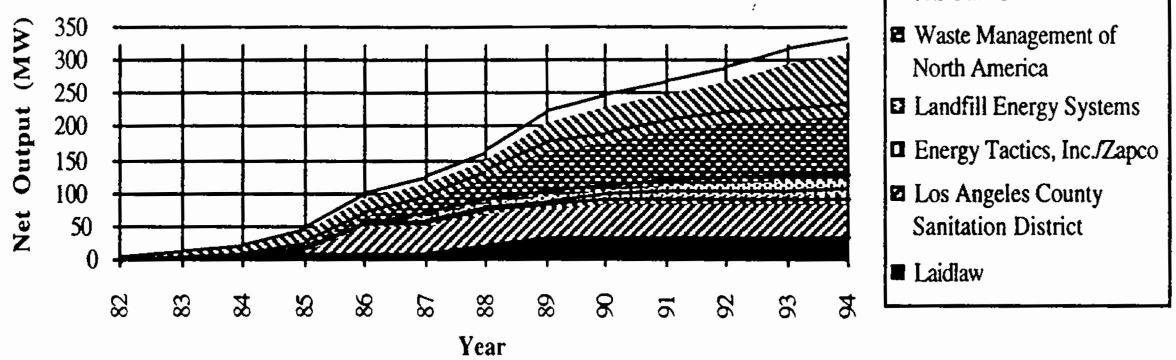


Figure 4. Net electrical output in MW by developer and year



Project economics: A new point of view on project economics is that the landfill owner shares the cost of developing the project with the LFG developer who helps offset the regulatory control costs. In the past the developer was responsible for all costs, and LFG-to-energy projects were considered as a pollution source rather than pollution prevention. The EPA does consider LFG-to-energy projects as pollution prevention, and therefore offsets can be considered by states in permitting projects in nonattainment areas. Historically, developers were responsible for all costs for a new project including permitting, legal fees, administrative, engineering, gas extraction wells, blower (or compressor), energy equipment, and royalties. The CAA requirements will result in up to 400 sites to extract, collect and combust LFG emissions. Although the cost of energy is low, resulting in less revenue for new projects, an increase in new projects is anticipated. Also there seems to be a recognition of the pollution prevention benefits such as the offset of fossil fuel emissions and the conservation of fossil fuel. Many communities are recognizing that potential control costs can be offset and are working with developers to develop mutually beneficial projects.

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 by today's lenders. The amount of LFG over a period of 15 years or more can be estimated more reliably now than 20 years ago. However, often the kind of information that one needs, such as the amount of waste in a landfill, waste composition, acceptance rate over time, and age of waste in different areas of landfill, is not readily available or not reliable. For those, and many more reasons, estimates of LFG generation are generally expressed in a range. Financial institutions want reliable estimates of LFG potential to projected rates of return. However, a 20 to 30% difference may be the difference in profit or loss, and modeling LFG potential is often much less certain. Probably the main reason for projects to shut down has been inadequate gas quantities to support the energy equipment. Many developers are going to module skid-mounted systems so that equipment can be readily transferred to match gas availability. Many financial institutions consider LFG-to-energy projects somewhat as a high risk. However, as the environmental externalities are considered, the number of LFG-to-energy projects are likely to increase in the future. On occasion the equipment manufacturer/supplier will assist in the project; utility subsidiary companies have assisted in financing and project development. Several non-regulated utility subsidiaries are currently active in LFG project development.

Barriers and incentives: The soon-to-be-final CAA regulations for new and existing MSW landfills will help to encourage new LFG-to-energy projects. In addition, EPA's Landfill Methane Outreach Program was initiated to encourage new projects by working with states and utilities.

EPA/APPCD research has been directed to provide information of benefit to landfill owner/operators and to encourage innovative technologies.

Potential barriers to 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 by-product emissions (e.g., nitrogen oxides and carbon monoxide) for projects located in nonattainment regions. (New Source Review does consider these projects to be pollution prevention projects and provides opportunity for states to consider offsets for these projects. A methodology has been developed by EPA/APPCD that will allow for quantification of these pollution prevention benefits. This report is expected to be released soon.)
- difficulties in obtaining "attractive" power contracts with local utilities who are often primarily interested in purchasing low-cost power without considering environmental externalities (e.g., offsets from power plants using fossil fuel) [Several developers indicated that they were finding it increasingly challenging to obtain project revenues that cover operating and maintenance, debt service, royalty payments, and acceptable rate of return], and
- taxation by some states, such as California and Michigan, on LFG extraction and energy conversion facilities.

Energy costs have varied over time and are different across North America. They vary 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.

For the most part, LFG users must be near the landfill, as it is costly to install pipelines for transport offsite. This is what makes electricity production the most favored of LFG-to-energy conversion projects: electricity distribution lines are usually near the landfill. The pricing structure should be reasonably stable and sufficient to support project economics which include costs, debt service, royalty payments to the landfill owner, and an acceptable rate of return to the developer/investors for privately owned projects (McGuigan et al., 1995).

Many 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 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). Recent steps taken by EPA to consolidate regulatory requirements into one permit will hopefully prevent some of these difficulties in the future.

Factors that help to encourage such projects in the U.S. include: 1) Production Tax Credits (PTCs); 2) favorable utility contracts for electricity projects; 3) tax exemptions for LFG extraction and energy conversion facilities; 4) Renewable Energy Production Incentives in the Energy Policy Act of 1992; and 5) future availability of retail electricity wheeling.

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. These PTCs are currently worth about 1.3 cents/kWh sold and are equivalent to a dollar for dollar tax value. The PTC benefit is scheduled to phase out in the year 2002 or 2007, depending on the date of extraction system startup for projects installed prior to the end of 1996. Congress will have to decide if these extensions are to be continued.

States can help to encourage projects by requiring utilities to pay incentive rates to LFG projects and by mandating a certain level of capacity be derived from LFG projects. States can also exclude the LFG-related energy conversion systems from state taxation. Some utilities are encouraging LFG energy conversion projects by participating in their development and are joining in ventures to encourage LFG development.

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 many 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, and
- the project is staffed by experienced personnel and there is backup for servicing of the LFG extraction and energy conversion systems.

Some companies provide turnkey design/construction for energy conversion units and will provide the O&M activity as well; some provide the same turnkey service for the extraction systems. The service industry is expected to increase in response to potential CAA regulatory requirements. The EPA report (Doorn, Pacey, and Augenstein, 1995) lists the companies that provide different services related to LFG-to-energy project development, construction, and O&M.

TECHNICAL ISSUES AND REMEDIES

In response to concerns about new projects having to undergo the learning curve that many of the landfill owner and operators of LFG-to-energy projects have experienced, EPA/APPCD conducted a review of the major LFG technical issues and remedies. EPA/APPCD interviewed the major developers and operators, and copies of the transcripts and a summary of the information are contained in a recently completed EPA report (Doorn, Pacey, and Augenstein, 1995). This information was developed to help new projects avoid some of the issues that may arise and to show how these issues are being resolved or minimized. Many of the technologies that are used for LFG energy conversion projects have been adapted or modified for use on LFG versus natural gas. Technical issues can arise as the result of the relatively low heating value, from the presence of chlorinated and toxic compounds or particulates, or the formation of condensates or deposits. For LFG the heating value is approximately 19×10^6 joules/m^3 and for natural gas it is approximately 37 joules/m^3 (500 vs. 1,000 Btu/scf). The EPA report provides an overview of the technical issues and solutions that the developers and operators have found through field experience for LFG utilization in boilers, processes for upgrading LFG, reciprocating engines and turbines. Table 1 summarizes the principal technical issues, effects, and possible remedies.

Material modifications: For gas pretreatment, simple rules include preventing condensate as much as possible and avoiding carbon steel where an aqueous phase might occur. When used in low pressure situations [i.e., less than 70×10^3 Pa (10 psi)], carbon steel users may coat the steel with corrosion-resistant plastic or use polyvinyl chloride (PVC) and polyethylene. Most designs stipulate the use of stainless steel piping between the blower (or compressor) and the engine. 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.

TABLE 1. LFG TECHNICAL ISSUES, EFFECTS, AND POSSIBLE REMEDIES

System Part	Effect	Remedy
CORROSIVE GAS		
General		Condensate management
All Metal	Corrosion	Avoid carbon steel
Compressors	Corroded valve parts may enter	Modify valve assembly and/or replace parts frequently
IC Engines		Use oils and lubricants with high total base number
CONDENSATE		
	Line blockage/ Slugs	Condensate traps and drains and/or Temperature management and/or Removal of contaminants with solvents
	Disposal problem	
VARIABLE GAS FLOW		
General	Poor performance due to variable flow and quality	Extraction system management
LOW HEAT VALUE (compared to natural gas)		
Engines	Lower combustion temperature	Adjust fuel/air ratio
Boilers	Slower flame front propagation	Adjust burner

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 direct drainage to a low point, where the liquid is collected in condensate traps. To protect the motor, blower, or compressor unit from a sudden large charge of condensate originating in the extraction system, a condensate interceptor tank [3,785 liters (1,000 gallons) or larger] is usually placed inline directly ahead of the blower or compressor.

Management may elect to cool the gas slightly, refrigerate it to slightly above freezing, or cool it to - 30 or 35°C (- 20 or 30°F). Compression (with aftercooling), refrigeration, and cooling to - 30 or 35°C 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 that absorbs heat from the gas leaving the blower. 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).

To remove water vapor, a chemical desiccant, such as glycol or silica, may be used for those processes where LFG is being upgraded for use as pipeline quality gas or as vehicular fuel. Several more rigorous cleanup methods may also be applied to remove stubborn contaminants.

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 impending 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/APPCD has developed a case study on lubrication of spark ignition engines at the Stewartby site in the United Kingdom.

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.

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 carburation 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.

FIELD EXPERIENCE

Boilers: The most common approach to gas cleanup is to apply minimum gas cleanup, limited to condensate knockout and optional particulate filtration. The design needs to be adjusted for the lower energy content of the LFG flow, an approximate doubling of burner orifice area (at constant fuel delivery pressure).

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/APPCD report on LFG utilization (Augenstein and Pacey, 1992). Minimal gas cleanup is employed [condensate simply drops out of a low point in the 1210 m (3/4-mi) 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 the boiler has functioned well to date. Some corrosion of the inner door and external pipe fittings did occur, but replacement cost of the components is relatively low.

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 and particulate filtration. 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, including chromed valves and hardened piston rings, were applied to ameliorate problems. However, in one case, operating experience improved only when refrigerated gas cleanup was applied. Minimal cleanup regimens may suffice under certain conditions; e.g., 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). Marina recently added an engine and modified the pretreatment system to include particulate filtration, gas cooling, and heating.

Today's engines are relatively low pressure systems requiring low pressure [< 14×10^3 Pa (< 2 psi)] LFG delivery to the engines. This has eliminated the need for compressors with their associated high capital cost and maintenance. A major operator has recently published details of its experience and has provided further information in response to the survey conducted by EPA/APPCD (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 [~7×10^3 to 50×10^3 Pa (~1 to 7 psi)] to low-pressure engines with positive displacement Roots blower,
- 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.

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. Turbine materials have not been modified, 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 is normal with conventional fuels.

A typical cleanup sequence would be:

- Knockout tank,
- Stainless steel wire mesh pad, or coalescing filter,
- LFG compression to 1.2×10^6 Pa (175 psig),
- Separation of oil from compressed gas,
- Gas cooling by air heat exchange,
- Condensate removal by filtration,
- Reheat, and
- Final filtration.

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), and
- 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.

EMERGING TECHNOLOGIES

An EPA report is being developed based on EPA research conducted by APPCD. This report is expected to be available soon. It provides a critical review of the different technologies that are being demonstrated in field- and/or bench-scale LFG demonstration projects which include fuel cells, production of compressed natural gas for vehicle fuel, production of methanol, and production of commercial CO_2 and liquefied natural gas. Other potentially applicable technologies that are discussed include Stirling cycle and organic Rankine cycle. For each technology or process, the report provides an overview, process description, and information on its extent of use, performance, potential emission reduction capability, potential for by-product emission, economics, and technical issues. Provided below is a brief description of three technologies that are being field demonstrated in the U.S.

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 x 10^6 liters (3 x 10^6 scf) 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.

Fuel cells: Fuel cells have been a well established technology for using natural gas to generate energy for more than 20 years. 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. The gas cleanup system is designed to clean the gas to 3 ppmv of chlorides and 3 ppmv of sulfur (Sandelli, 1992). The gas cleanup system has operated over 2,600 hours with no problems and producing gas of quality at 0.001 ppmv which is much better than the design specifications. The fuel cell operated for 4 months on LFG, and plans are being made to move it to a new site where fuel cell waste heat and cleanup system gas will be utilized as boiler fuel. In addition, plans are to provide power both on and off grid. As a result of this demonstration project, Northeast Utilities plans to install 1 MW of fuel cells in the Hartford, Connecticut, landfill. Several other utilities have expressed interest in the fuel cell for LFG applications.

The major nontechnical 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/kW by 1998. This should result in making the fuel cell competitive with conventional technologies in use today. However, as more fuel cells are utilized, their capital cost is expected to decrease.

Recovery of waste heat from LFG combustion and leachate treatment: Another emerging technology is on-site LFG combustion in an evaporation system to evaporate leachate. Other on-site uses are likely to evolve such as using small boilers for hot water, steam, and heating, and small IC engines to offset some, or all, site electricity use, and space heating. These uses will help offset on-site energy needs, and perhaps an adjacent, or nearby, customer may be found with similar needs. Landfill owners/operators will be looking for opportunities to defray costs, particularly since post-closure costs will generally extend 30 years after actual closure, and utilization of LFG-to-recovery waste heat and/or leachate treatment can help to offset costs.

SUMMARY

This paper describes EPA/APPCD'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 the major developers and operators in LFG utilization project development, operations, and/or management in the U.S. In addition, we provided summaries of recent data from an EPA/SWANA database for LFG-to-energy projects. Although solutions to many of the technical issues facing this industry are being found, nontechnical issues are considered by the developers and operators to be of more concern such as potentially low revenue for new projects due to low energy costs. However, soon-to-be-final regulations for LFG emissions, EPA research activities, and EPA's Landfill Methane Outreach Program, are working to help encourage new projects. As a result, an increase in new projects is anticipated which will be tracked in future updates of the EPA/SWANA database of LFG-to-energy projects. 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 summarizes ongoing EPA research on landfill gas (LFG) utilization. Research was conducted to identify technical issues and solutions through interviews conducted with industry experts in the U.S., Europe, and Australia. The U.S. developers and operators who were interviewed represent more than 70% of all the projects in the U.S. Technical issues associated with the use of LFG as compared to natural gas can result due to chlorinated and toxic compounds, particulate, and reduced heating value when compared to natural gas (18.6 million vs. 37.2 million joules/cu m). A recent database of LFG-to-energy projects that has been developed through a collaborative program between EPA and the Solid Waste Association of North America (SWANA) indicates that, as of December 1994, there were 137 LFG-to-energy projects in the U.S. and 9 in Canada. The paper provides summary statistics and industry trends resulting from this database, and a discussion of the nontechnical and technical issues and solutions. Other EPA research discussed is a recent overview of emerging technologies for LFG utilization and research regarding the demonstration of fuel cells for LFG utilization. The research described is part of a larger EPA research program to develop more reliable emission estimates for the major sources of greenhouse gas emissions.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Fuel Cells	Pollution Prevention	13B	10B
Earth Fills		Stationary Sources	13C	
Gases		Landfill Gas	07D	
Energy			14G	
Data				
Greenhouse Effect			04A	

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