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Landfill Gas Utilization - Options, Benefits, and Barriers

Susan A. Thorneloe (MD-63)
Global Emissions and Control Division
Air and Energy Engineering Research Laboratory
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

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ABSTRACT

Of the more than 6,000 active municipal solid waste landfills in the United States (U.S.), there are 114 landfill gas (LFG) to energy projects. This paper describes the different options for LFG to energy projects and provides statistics on the U.S. LFG industry. This paper also provides an overview of the benefits associated with LFG utilization and identifies some of the current barriers in the U.S. that affect LFG utilization. The support for this research is from the U.S. Environmental Protection Agency's (EPA's) Global Climate Change Program on emissions and mitigation from landfills and other waste management facilities that produce greenhouse gases. EPA's Air and Energy Engineering Research Laboratory (AEERL) has responsibility for EPA's research on emissions and mitigation for the major sources contributing to global climate change.

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Global Emissions and Control Division (MD-63)
Air and Energy Engineering Research Laboratory
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Introduction

Of the more than 6,000 active municipal solid waste (MSW) landfills in the United States (U.S.), there are 114 landfill gas (LFG) to energy projects. This paper describes the different options for LFG to energy projects and provides statistics on the U.S. LFG industry. This paper also provides an overview of the benefits associated with LFG utilization and identifies some of the current barriers in the U.S. that affect LFG utilization. The support for this research is from the U.S. Environmental Protection Agency's (EPA's) Global Climate Change Program on emissions and mitigation from landfills and other waste management facilities that produce greenhouse gases (Thorneloe, 1991). EPA's Air and Energy Engineering Research Laboratory (AEERL) has responsibility for EPA's research on emissions and mitigation for the major sources contributing to global climate change. Landfills are considered a significant contributor of methane (CH_4) emissions and are being considered for control in negotiations regarding global climate change (U.S. EPA, 1989).

Energy Utilization Options

Landfill gas results from the anaerobic decomposition of landfilled waste and can be a source of pollution as well as a resource. The composition of LFG is typically 50 to 55% CH_4, 45 to 50% carbon dioxide (CO_2), and <1% nonmethane organic compounds (NMOCs). The concentration of NMOCs can range from 240 to 14,300 ppm (U.S.EPA, 1991). LFG can also contain chlorinated and fluorinated compounds, particulate, water vapor, and occasionally air. Air infiltration is minimized because it (1) can kill the anaerobic bacteria that are needed to decompose organic refuse, (2) can cause landfill fires, and (3) dilutes the gas which increases the cost of recovering energy from the gas.

The average heating value of LFG ranges from 17 to 20 MJ/dscm (450 to 550 Btu/dscf). Laidlaw Technologies, Inc., with responsibility for 12 LFG energy recovery projects, estimates that between 1,250 and 1,600 kW_e of energy is generated from 28,000 scmd (1 million scfd) of LFG at 17 MJ/scm (450 Btu/scf) (Jansen, 1992). Consequently LFG is recovered to take advantage of the energy potential. This results in reducing emissions of CH_4, NMOCs, and toxics. In addition, emissions are reduced at coal-fired power plants, and global resources of fossil fuel are conserved.

The EPA's AEERL initiated a project in 1991 to document the options for LFG utilization. This work included gathering data on the operating and maintenance requirements, the financing and contractual arrangements, and "lessons learned" from the six sites included as case studies. A summary of this work (Thorneloe, 1992) includes a list of U.S. LFG to energy projects. The final report being prepared by Emcon Associates will contain detailed information for six U.S. LFG to energy projects including capital and operating costs, process flow diagrams, and data regarding the environmental benefits of LFG utilization. This section provides a brief overview of the options for LFG utilization and a summary of the results of the EPA survey of LFG to energy projects.

The EPA survey identified 114 LFG to energy projects in the U.S.(Thorneloe, 1992). Detailed results of this EPA survey are scheduled to be published this fall. This survey was conducted in coordination with the Solid Waste Association of North America (SWANA). Figure 1 provides a breakdown of the types of LFG to energy projects in the U.S. Most of the projects (i.e., ~75%) generate electricity which is either used on-site or sold to a local utility. Of the projects generating electricity, approximately 344 MW_e of power is being produced with 61 projects using internal combustion (IC) engines, 21 projects using gas-fed turbines, and 3 projects using steam-fed turbines. Pipeline quality gas is produced at six sites, and one site is processing LFG to produce diesel fuel. The most economical options for LFG utilization tend to be direct uses such as for process heat and as boiler fuel. Direct use of LFG as medium-heating value fuel is occurring at 21 sites.

Figure 2 provides a breakdown of the U.S. LFG to energy projects by state indicating the number of projects for states where there are at least three active LFG utilization projects. California has the largest number of LFG to energy projects partially due to state and local requirements resulting in the collection and control of gas. However, many LFG to energy projects have been initiated because of attractive economics particularly in the early 1980s when the price of energy helped make this more economical. Waste Management of North America has installed gas collection and controls as part of their operating policy. Waste Management has LFG to energy projects at 25 sites with plans to start new projects at 5 additional sites (Markham, 1992). The Clean Air Act regulations proposed May 30, 1991, are expected to result in additional LFG utilization projects.

Direct-Gas Use (Medium-Heating Value). The options for medium-heating value LFG [i.e., ~19 MJ/ "dry" scm (~500 Btu/dscf)] include use as boiler fuel, space heating and cooling, and industrial heating/cofiring applications. The most typical use is as boiler fuel to produce steam. The majority of the 21 sites selling LFG for direct use are supplying fuel for boilers. This is a particularly attractive option since conventional equipment can be used with relatively little modification. In addition, boilers tend to be less sensitive to LFG trace constituents and consequently less gas cleanup is required compared to the other alternatives. A limitation in the selection of this option is that a LFG customer must be relatively near, typically less than 1,600 to 3,200 meters (1 to 2 miles) is considered desirable to avoid excessive costs and difficulties obtaining access.

The other options for medium-heating value gas include industrial applications such as lumber drying, kiln operations, and cement manufacturing. An advantage of many industrial applications

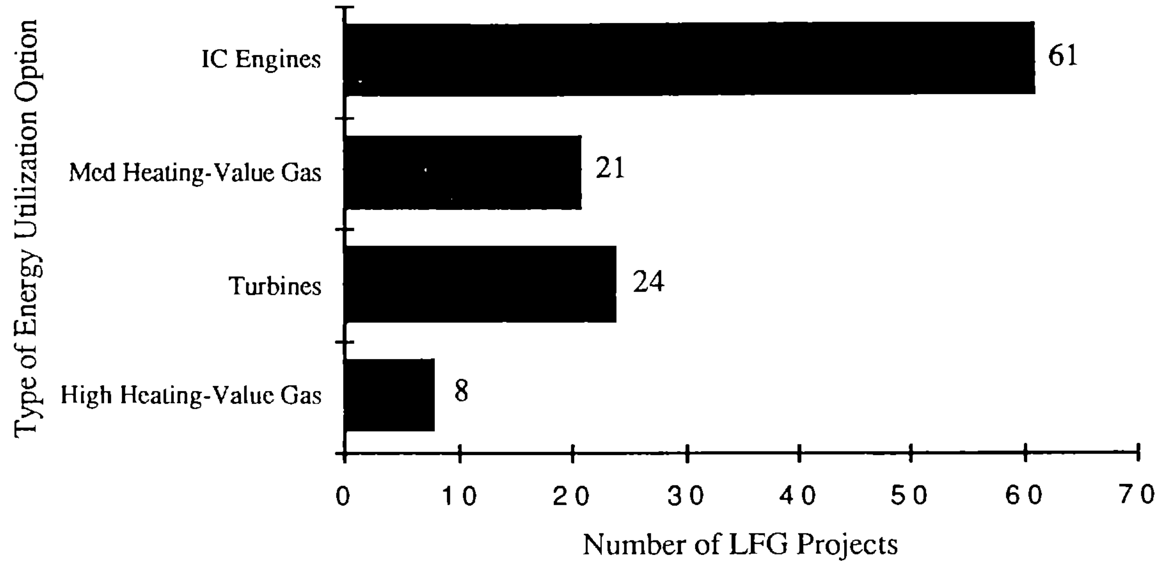

Figure 1. Number of U.S. Landfill Gas Projects by Energy Utilization Option

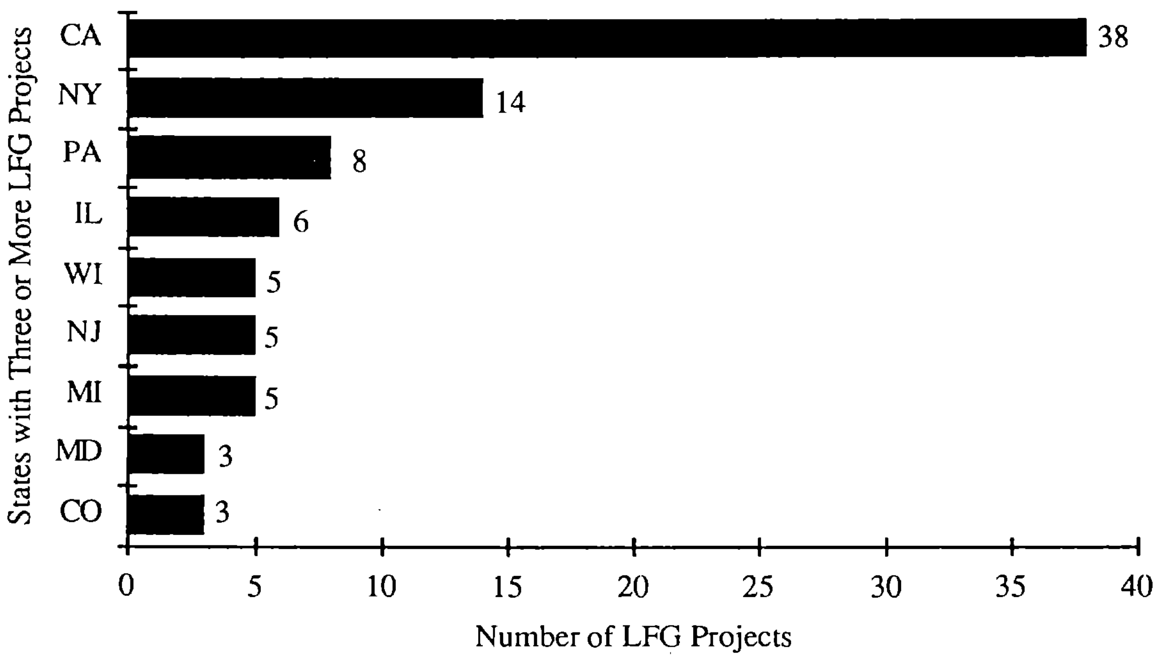

Figure 2. Number of U.S. Landfill Gas Projects by State
for those States with Three or More Projects

is that fuel is required continuously, 24 hours per day. LFG can also be used as a supplemental fuel that meets a portion of the total demand. LFG to produce space heating is in limited use primarily due to piping costs and difficulty in matching up the LFG energy output with nearby user needs. Depending on climate and other factors, heat energy supplied by 14,000 scm/d (500,000 scf/d) LFG corresponds to heating needs of an 18,600 to 93,000 m^2 (200,000 to 1,000,000 ft^2) facility. The main difficulty with space heating is that loads tend to be variable over time, both during the day and by season.

Electricity Generation. Of the 114 U.S. LFG to energy projects, 61 projects generate electricity using IC engines and 24 projects generate electricity using turbines. Of the 344 MW_e of electricity produced at these sites, 51% is generated using turbines and 49% is generated using IC engines. The type of equipment is generally determined by the volume of gas available and the air pollution requirements of the area in which the project is located. The rule of thumb for the selection of engines versus turbines is that engine projects are typically used at sites where gas quantity is capable of producing 1 to 3 MW_e. Turbines are typically used at sites producing more than 3 MW_e (Jansen, 1992). Typically there are three to five engines per project and one to two turbines per project. The distribution of U.S. LFG to energy projects based on gross output is:

	Number of Projects Using:	
MW_e	Turbines	IC Engines
1-5	12	54
5-10	10	3
10-15	1	3
15-20	0	1
20-25	0	0
25-30	0	0
30-35	0	0
35-40	0	0
40-45	0	0
45-50	1	0
TOTAL	24	61

Reciprocating IC engines drive electrical generators to produce electrical power which is typically sold to the local electric utility. Engines used in this application are sold by three manufacturers - Caterpillar, Cooper-Superior, and Waukesha. Each of the 3 manufacturers has in place more than 20 engines at U.S. landfill sites (GRCDA, 1989). These manufacturers design engines that are specific to LFG applications (i.e., corrosion resistant). Typically, warranties that guarantee engine performance require the operator to agree to certain conditions regarding engine operation and maintenance.

Reciprocating engines used for LFG applications may be either stoichiometric combustion or lean combustion engines. The "lean-burn" engines are turbocharged and burn fuel with excess air. The stoichiometrically carbureted or "naturally aspirated" engines have air in the fuel/air mix just sufficient to burn the fuel. The lean-burn engines are typically used where nitrogen oxides (NO_x) and carbon monoxide (CO) emissions are of concern. Stoichiometric combustion can result in relatively high NO_x emissions which can vary widely due to carburetor setting and other variables.

Another factor to consider is that there is a trade-off between low NO_x emissions and the reduction of NMOCs.

Gas-fed turbines are also used at landfills to generate electricity. Gas turbines take large amounts of air from the atmosphere, compress it, burn fuel to heat it, then expand it in the power turbine to develop shaft horsepower. This horsepower can be used to drive pumps, compressors, or electrical generators (McGee and Esbeck, 1988). Gas turbines are used at 21 U.S. landfills to produce 108 MW_e of power. Waste Management of North America, Inc. has found that gas-fed turbines typically have parasitic energy losses of 17% of gross output as compared to 7% for IC engines. A factor to consider is that turndown performance is poor in comparison to that of IC engines. Turbines perform best when operated at full load, and difficulties can occur when operated at less than full load. In addition, trace constituents have been reported to cause corrosion, combustion chamber melting, and deposits on blades. However, these difficulties can be overcome as demonstrated by Waste Management of North America (Schlotthauer, 1991).

Steam-fed turbines are in use at three sites to produce 64 MW_e of power. The largest LFG to energy plant is the Puente Hills Energy Recovery from Gas facility (PERG), located at the Puente Hills Landfill in Whittier, California. This site began recovering LFG for energy utilization in November 1986. It is operated by the Los Angeles County Sanitation Districts. The facility consists of twin Zurn Industries, Inc. gas-fired steam generators. Each of the units fires 420,000 scmd (10,300 scfm) of LFG, producing 95,340 kg (210,000 lb) of steam per hour at 9.3 MPa (1350 psig), heated to 540°C (1000°F). This steam drives a Fuji Electric Co. Ltd. turbine that generates approximately 50 MW_e net, that is sold to Southern California Edison (Valenti, 1992).

High-Heating Value Gas. Seven sites in the U.S. upgrade LFG to pipeline quality. This option was considered more attractive in the early 1980s when the price of oil and natural gas helped make this more economical. The sites that are producing pipeline quality gas were initiated in the early 1980s when gas prices on a heating-value basis were comparable with those of oil. These sites have an average LFG flow rate of 142,000 scmd (5 million scfd) with the lowest gas flow rate being 31,150 scmd (1.1 million scfd) and the highest being 269,000 scmd (9.5 million scfd). Stringent cleanup technology is applied to purify the gas to pipeline quality by removing the trace constituents and CO_2. Similar to the medium-heating value applications, a nearby natural gas pipeline is needed. The largest operator of facilities producing pipeline quality gas from LFG is Air Products and Chemicals, Inc. Low natural gas prices in the late 1980s forced several previous projects to shut down, and continue to inhibit the development of new high-heating value projects in the U.S. However, sites in the Netherlands are finding more favorable economics (Scheepers, 1991).

A site that began operation last year in Pueblo, Colorado, is producing liquid diesel fuel from LFG. This site is operated by Fuel Resources Development, Inc. and began producing commercial product in January. A second site in the U.S. may be used 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. TeraMeth Industries is responsible for the demonstration, and research is being coordinated with the EPA. The demonstration is anticipated to begin in 1993.

Other Options for Landfill Gas. Fuel cells are a potentially attractive option for LFG because of higher energy efficiency, availability to smaller as well as larger landfills, and recognition for minimal byproduct emissions. Other advantages include minimal labor and maintenance, and (because there are no moving parts) the noise impact is minimal. Hydrogen from the landfill gas is combined electrochemically with oxygen from the air to produce dc electricity and by-product water. The fuel cell is designed for automatic, unattended operation, and can be remotely monitored. The EPA's AEERL initiated a project in 1991 to demonstrate the use of fuel cells for LFG application. The type of fuel cell being demonstrated is a commercially available 200 kW_e phosphoric acid fuel cell power plant. The 1-year full-scale demonstration is scheduled for 1993.

The major issue associated with this demonstration is designing a LFG cleanup process that will remove the trace constituents from the LFG and at the same time not be cost prohibitive. Since the composition of LFG varies over time, designing a process that can allow for this variability is difficult. A cleanup process has been proposed and is to be evaluated later this year. The fuel pretreatment system incorporates two stages of refrigeration combined with three regenerable adsorbent steps (Sandelli, 1992). It is hoped that, if the EPA demonstration of the use of fuel cells is successful, more landfill owner/operators will consider fuel cells as an option for LFG utilization. Given the higher energy efficiency and potential for minimal byproduct emissions, fuel cells may be the most attractive option for areas where there are stringent requirements for NO_x and CO emissions.

Benefits of Landfill Gas Utilization

The five major health and welfare effects of air emissions from MSW landfills are (1) explosion hazards, (2) global warming effects from CH_4 emissions, (3) human health and vegetation effects caused by ozone formed from NMOCs, (4) carcinogenicity and other possible noncancer health effects associated with specific MSW landfill emission constituents, and (5) odor nuisance. The first concern, the explosive potential of LFG, has resulted in 40 cases of gas migration in the U.S. which have resulted in explosions and fires. Of these 40 cases, 10 resulted in injuries and death (U.S.EPA, 1991). The second concern is the contribution of landfill CH_4 to global warming. Landfills are a significant source of CH_4, ranking third in anthropogenic sources after rice paddies and ruminants (Peer et al., 1992, Khalil and Rasmussen, 1990). A third concern is the contribution of NMOCs to tropospheric ozone which affects human health and vegetation. The EPA has estimated that roughly 1% (i.e., 260,000 Mg/yr) of the NMOC emissions from stationary sources in the U.S. are emitted by MSW landfills. Toxic constituents typically found in LFG include vinyl chloride, toluene, and benzene which may contribute to possible cancer and non-cancer health effects. The fifth concern is the odor nuisance associated with LFG. Because of the health and environmental concerns, the EPA has designated "MSW landfill emissions" as a pollutant to be regulated under Sections 111(b) and 111(d) of the Clean Air Act. The EPA has proposed Emission Guidelines for existing landfills and New Source Performance Standards for new landfills (Federal Register, 1991). The regulations are scheduled to be promulgated this Fall.

The regulatory alternative proposed by the Clean Air Act regulations would result in requiring 621 landfills to collect and control MSW landfill emissions (p. 24480, Federal Register, 1991). Although the rule does not require utilization of the gas, it is hoped that the sites affected by these regulations will consider LFG to energy as opposed to flaring the gas. The use of energy recovery for the control of MSW landfill air emissions will result in decreased emissions of CH_4, NMOCs, and toxics. In addition, emissions are reduced at coal-fired power plants, and global resources of fossil fuel are conserved. Although increased CO_2 emissions are being traded off for reduced CH_4 emissions, this is a net benefit due to the difference in the radiative forcing capacity between CO_2 and CH_4. The radiative forcing capacity of CH_4 to CO_2 on a molecular basis is 21 times that of CO_2 (p. 53, IPCC, 1990).

There are also benefits associated with the development of an alternative source of energy which results in decreased emissions at coal-fired power plants, conservation of fossil fuel resources, and reduced dependence on imported oil. In addition, LFG utilization can result in a substantial cost savings to public entities that own the landfill as well as royalty payments. For example, Pacific Energy - who has developed 25 LFG energy projects - has paid out $13 million in royalties, mostly to public entities. On average, Pacific Energy's projects are in the sixth year of operation under anticipated twenty-year project lives (Wong, 1992). Other economic benefits include the purchase of goods and services. In 1991, Pacific Energy purchased over $4 million in outside goods and services to support its LFG projects plus a payroll of >$3 million. LFG to energy projects tend to be capital intensive and are typically built on what is considered undevelopable acreage. Pacific Energy's eight LFG to energy projects in California pay >$350,000 per year in property taxes in California and require few public services (Wong, 1992).

Barriers to Landfill Gas Utilization

A major factor in helping to encourage LFG to energy projects is the Public Utility Regulatory Policy Act (PURPA). It guarantees that utilities purchase power that was generated from landfills at a price related to the costs that utility would experience to produce the same amount of power. Although this guarantees a purchaser for the power, the power sale revenues may be low if the utilities' own generating costs are low. In addition, tax credits have been available that also encourage renewable energy projects, such as LFG utilization. However, current trends are toward lower energy prices, reduced tax incentives, and increasing environmental liability.

Although there are more than 6000 landfills in the U.S., there are less than 120 LFG to energy projects. During the oil crisis in the 1970s/1980s when the price of oil increased from $6-8 per barrel to $35 per barrel, there was much more interest in developing alternative sources of energy, including utilization of landfill gas. With the current prices of energy, it is much more difficult to find projects that are economical. More than 30 U.S. projects have had to cease operation due to economics. Many of the projects that were upgrading to pipeline quality are no longer in operation primarily due to economics. The pipeline cost can be excessive which is why sites tend not to transport the gas farther than 1,600 to 3,200 meters (1 to 2 miles).

Laidlaw Technology Inc. suggests that "successful" LFG projects need to be over 1 MW_e and have an electrical price of at least $0.06-0.07/kWh including any capacity payments. Royalties should not exceed 12.5% at this energy pricing (Jansen, 1992). Laidlaw also suggests that, if higher royalties are offered, the percentage should be a function of energy pricing over and above the base energy rate as inflation occurs. The early LFG projects were based on an established firm price for net energy which provided a substantial degree of security to developers. Contracts for many LFG projects do not allow for fluctuations in energy rates and costs. Revenues for energy sales are usually based on prices of the "competition" of equivalent energy sources (e.g., petroleum products). Since the value of the energy base commodity can fluctuate, this can impact profit.

Administration and development costs have increased as revenues have decreased. Administrative and development costs include legal fees, permit applications, and contract negotiations including gas lease agreements and power purchase agreements. These costs may vary widely depending on the environmental issues, development considerations, and regulatory requirements. John Pacey of Emcon Associates has found that these costs can vary from $30,000 to $1,000,000 per kWh for a 1 MW_e LFG energy project.

Tax credits are benefits proportional to gas energy delivery which were legislated by Congress (Section 29 of the IRS Code) in 1979 to encourage non-fossil fuel use. These credits are a direct offset to taxes and can only be used to offset a profit. The tax credits will extend to the year 2003 and are allowable for extraction systems installed prior to the end of the year 1992. However, the most recent version of the tax bill being considered by Congress does not provide an extension for these tax credits. Robert F. Hatch of Cambrian Energy Systems - whose company has been involved in arranging financing for many U.S. LFG to energy projects - thinks that many of the projects would not be in existence if the tax credits were not available. Some projects today are financed only because of the tax credits since energy prices are relatively low. The tax credits help promote the development of a domestic resource as opposed to using foreign oil (Hatch, 1991). These tax credits help to encourage LFG to energy projects and also help municipalities defray the cost of environmental regulations.

Another barrier to LFG utilization can be environmental regulations. Unfortunately, the overall environmental benefit of utilizing LFG is not necessarily considered, let alone energy and economic benefits. George Jansen of Laidlaw Technologies is finding that the cost of condensate disposal is becoming a major expense. The condensate is formed when the gas is compressed. The LFG condensate is being classified as a hazardous waste which requires disposal at a Subtitle C facility. This cost [i.e., $0.18/L (~$0.70/gal)] can be significant for a site where lean-burn engines or turbines are used as compared to the use of flares where minimal condensate is collected (3,800 L/day (1000 gpd) for lean-burn engines or turbines versus 760 L/day (200 gpd) for flares) (Jansen, 1992).

Some LFG energy industry experts have found that the air, water, and solid waste agencies have conflicting goals. LFG energy projects have been forced to shut down due to concerns for by-product emissions of NO_x and CO. In California last year, 48 pieces of state legislation affecting solid waste were enacted (SWANA, 1992). Priorities often appear to conflict. There has been extensive coordination between the EPA Offices responsible for the Subtitle D regulations (e.g., Office of Solid Waste) and the proposed CAA regulations (e.g., Office of Air Quality Planning Standards) for MSW landfills to ensure that these regulations are complementary. However, additional effort appears needed to evaluate what can be done to help encourage and promote LFG to energy projects.

Conclusions

U.S. LFG to energy projects are currently recovering approximately 1.2 million tonnes of CH_4 and producing 344 MW_e of power. The proposed CAA regulations for MSW landfill air emissions are expected to result in additional emission reductions ranging from 5 to 7 million tonnes of CH_4. Utilization of LFG for those sites affected by the proposed CAA regulations has the potential to result in increased benefits to our economy, energy resources, and global environment. The utilization of alternative energy sources such as LFG extends our global fossil fuel resources. Not only are emissions directly reduced when LFG is collected and recovered for utilization, but emissions are also indirectly reduced when secondary air emission impacts associated with fossil fuel use are considered.

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17. KEY WORDS AND DOCUMENT ANALYSIS

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