"NEXT GENERATION" TECHNOLOGIES FOR LANDFILL GAS AND "WHAT IS ETV?"

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Abstract: The United Stated Environmental Protection Agency's (EPA) Office of Research and Development (ORD) is responsible for evaluating the "next generation" of technologies for reducing greenhouse gas (GHG) emissions. A recently published report gave results of an EPA review of the next generation or emerging technologies for landfill gas (LFG) control and utilization. This paper provides a summary of the report. The Environmental Technology Verification (ETV) Program through EPA/ORD has been launched. Through this program, technology purchasers can have access to an objective source of data to make informed purchasing decisions. In addition, vendors who want to market their products on a "level playing field" will have objective credible data through ETV. As part of ETV, the EPA has formed a center for the verification of technologies that reduce GHG emissions. What is ETV and what does it mean to LFG? This paper provides the answers and points to further information on the program.

INTRODUCTION

There is a dramatic increase in the number of new and planned landfill gas to energy (LFG-E) projects in the U.S. Although we have fairly reliable information on the number of LFG-E projects, we do not have reliable information on the number of projects where LFG is flared. This increase in new projects is attributed to expiration of the date for obtaining federal tax credits and the promulgation on March 12, 1996, of New Source Performance Standards (NSPS) for new landfills and Emission Guidelines (EGs) for existing landfills to reduce LFG emissions (FR Volume 61, Number 49). Of the landfills expected to be constructed over the next 5 years, the EPA has estimated that about 45 will require LFG collection and control systems. For existing landfills with capacities greater than 2.5 x 10^6 megagrams of waste, approximately 300 will be required to install collection and control systems.

The regulations do not require the utilization of LFG to produce energy or other products. Recent information on the number of LFG-E projects in the U.S. indicates that the number of projects may increase from 200 to over 400 within the next few years. Although, the EPA does not require that LFG be utilized, it is interested in promoting LFG utilization where it is technically and economically feasible. In 1994, the EPA classified the control of LFG emissions as a pollution prevention source. This provides states the opportunity to consider offsets when permits are being obtained. (pp. K-8 – K-15 of Doorn et al., 1995). A methodology for quantifying these benefits was published in the EPA report, *Methodologies for Quantifying Pollution Prevention Benefits from Landfill Gas Control and Utilization* (Roe et al., 1995). Although flaring LFG is considered a pollution prevention source, additional environmental benefit is realized for sites where LFG is being utilized for its energy potential.

Concerns have been raised with the control of LFG due to the potential for by-product emissions such as carbon monoxide, nitrogen oxides (NO_x), and sulfur oxides, and the possible formation of dioxin/furans from the different combustion devices being used for LFG. Depending upon the geographical region where the project is located and if the region is in nonattainment status for any criteria pollutant, the type of technology selected can be affected. Current data available through the Agency do not have data specific to different technologies such as lean-burn versus rich-burn reciprocating engines (e.g., AP-42). Even within lean-burn engines, some of the more recent units have much lower NO_x emissions than previous models. Currently for some pollutants, we do not have adequate emissions and control data for the next generation technologies or even conventional technologies. Consequently, state and local regulatory agencies can require expensive tests when projects are being permitted to determine the emission reduction and potential for by-product emissions.

Of the pollutants of concern, dioxin/furan emissions are frequently mentioned. Several LFG-E projects have been tested for polychlorinated dibenzo-dioxins (PCDDs), dibenzo-furans (PCDFs), and polychlorinated biphenyls (PCBs). Test reports exist for two boilers, one flare, and one gas turbine (Doorn et al., 1995). For the flare, the gas turbine, and one of the boilers, the emissions results were all less than the detection limits for all of the above combustion products. The positive test result showed emission levels generally protective of public health (i.e., $<10^{7}$ lb/hr), however a laboratory blank also tested positive. Current thinking is that the combustion of LFG will not be a major source of PCDDs/PCDFs, compared to other processes that favor dioxin/furan formation. However, data are needed for the different types of combustion devices in use to be able to establish the emission levels of by-product emissions. These tests can be expensive (particularly measurements of PCDDs/PCDFs). To the extent the emission levels can be established, then it may reduce the costs of future projects being permitted.

The EPA/ORD's Air Pollution Prevention and Control Division has conducted several projects to help those impacted by the Clean Air Act regulations by providing assistance in resolving technical issues associated with LFG utilization. A series of reports have been published by EPA/ORD that help in the evaluation of technologies and technical issues associated with LFG control and utilization:

- *Landfill Gas Energy Utilization: Technology Options and Case Studies*, EPA-600/R-92-116, (Augenstein et al., 1992);
- *Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends*, EPA-600/R-95-035, (Doorn et al., 1995); and
- *Methodologies for Quantifying Pollution Prevention Benefits from Landfill Gas Control and Utilization*, EPA-600/R-95-089, (Roe et al., 1995).

In a recent report (Roe et al., 1998), EPA conducted an evaluation of the next generation technologies that are currently ready for commercialization, undergoing research and development (e.g., field- or bench-scale demonstrations), or are being considered as potentially applicable for the control or beneficial use of LFG. This report has been published and was developed through a series of site visits and contacts with LFG technology developers and operators.

CENTER FOR VERIFICATION OF TECHNOLOGIES THAT REDUCE GREENHOUSE GAS EMISSIONS

The Environmental Technology Verification Program (ETV) was established as a result of the needs expressed by numerous government and private groups for an organized and ongoing program to produce independent, credible performance data. Currently, the lack of this information is considered a major impediment to the development and use of innovative environmental technology. The goal of ETV is to verify the environmental performance characteristics of commercial-ready technology through the evaluation of objective and quality-assured data, so that potential purchasers and permitters are provided with an independent and credible assessment of what they are buying and permitting (U.S. EPA, 1997).

As part of ETV, the EPA established a Center in 1997 for verifying the reduction capability of different technologies that reduce GHG emissions. Funding to date for the Center is $3 million for fiscal years 1997 and 1998. Landfill methane has been identified as an initial priority. This provides an opportunity for landfill owner/operator/developers to have technologies evaluated for GHG reduction capability, energy efficiency, and potential for by-product emissions.

The types of technologies that could be considered include currently commercially available technologies as well as next generation technologies that are close to commercial application. Data resulting from this effort can then be used by manufacturers, vendors, regulators, permit applicants, and others in establishing the emission reduction capability of different technologies. Also data can be collected on all pollutants and are not limited to GHG emissions. This program has the opportunity of helping to establish the emission levels for potential by-product emissions as well as the emission reduction capability. The EPA is hosting stakeholder meetings to get input on the prioritization of technologies to evaluate. If you are interested in knowing more about this program contact either the web site at http://www.epa.gov/etv/ or the EPA project officer, David A. Kirchgessner at DKirchgessner@engineer.aeerl.epa.gov.

LANDFILL GAS TECHNOLOGIES

A database of LFG-E projects is being developed through the Database Committee of the Solid Waste Association of North America's Landfill Gas Division (Thorneloe, 1992). These data were presented at the 20th Annual Landfill Gas Symposium by Alex Roqueta and are summarized in Table 1 (Roqueta, 1997). This committee will be updating the information and releasing a report scheduled for completion in 1998. These data will help to track the trends that are occurring in the LFG industry.

Table 1. Operational or Planned LFG –E Projects

Technology	Operating Facilities	Construction./ Advanced Planning	Capacity Range of Installed Facilities (kW) or Equivalent
Reciprocating Engines	89	>30	80 – 12,300
Gas Turbines	22	4	740 – 16,500
Combined Cycle	2	1	13,600 – 20,500
Boiler/Steam Turbine	5	1	7,000 – 50,000
Medium Heating Value Fuel	27	11	300 – 17,000
High Heating Value/Vehicle Fuel	5	5	800 – 19,000

NOTE: kW = kilowatt, Adapted from Roqueta, 1997.

As a result of the increase in new projects, innovations in existing and next generation technologies are being considered for LFG applications. EPA/ORD has conducted a review of the potential technologies for managing and utilizing LFG. The purpose of this report is to present information on emerging technologies for managing or utilizing methane and carbon dioxide from municipal solid waste (MSW) landfills. Essentially, these are technologies other than those that have been in commercial use for at least several years. Examples of conventional LFG-E technologies are shown in Table 1 and include electricity generation with reciprocating internal combustion (RIC) engines and gas or steam turbines, and production of medium heating value fuel for input to boilers (for process or space heating).

OVERVIEW OF THE EPA REPORT ON EMERGING LFG TECHNOLOGIES

The technologies that are presented in the recently published EPA report are divided into three tiers. Tier 1 technologies are considered to be commercially available in the U.S. Tier 2 technologies are currently undergoing additional R&D or have been tested at the bench- or field-scale and may be ready for commercial application. Finally, Tier 3 technologies may have applicability to LFG utilization or management based on applications with similar fuel types (e.g., natural gas).

For technologies that are considered to be technically feasible at a commercial scale (Tier 1), the report provides an introduction and general overview of the demonstration project, a project history (of known projects), a process description, information on performance, a discussion of air emissions and secondary environmental impacts, and available information on project economics. For Tier 2 technologies, a process description and information on air emissions and costs follow an introduction and general overview of the technology. For the Tier 3 technologies, the report provides information on the process, current usage, potential for use on LFG, and potential air emissions and costs.

The development of LFG management and utilization technologies is ongoing, and we will continue tracking these technologies as new developments are made. Copies of the report can be obtained through the National Technical Information Service or through the EPA's Technology Transfer Network (TTN) web site: www.epa.gov/ttn/direct.html. The report is located under the Clean Air Technology Center, formerly known as the Control Technology Center.

COMMERCIALLY AVAILABLE (TIER 1) TECHNOLOGIES FOR LANDFILL GAS

Tier 1 technologies have been demonstrated at a commercial level and show promise for economic viability at various scales of application, including:

- Use of phosphoric acid fuel cells (PAFCs) for generating electricity and waste heat;
- Conversion of methane from LFG to compressed landfill gas (CLG) for vehicle fuel; and
- Utilization of methane from LFG to evaporate landfill leachate and LFG condensate.

Fuel cells may be compared to large electrical batteries (with ancillary equipment, such as catalysts) which provide a means to convert the chemical bonding energy of a chemical substance directly into electricity. The major difference between a battery and a fuel cell is that in a battery the reactants are being slowly depleted during utilization. In a fuel cell, fresh reactants (fuel) are continuously supplied to the cell. Many consider fuel cells as a preferred technology due to their energy efficiency (>40%), minimal by-product emissions and noise impact, modular design, and ability to operate in remote locations (Arthur D. Little, 1993). Although fuel cell technology has been well established on natural gas, it is only within the last decade that its application to LFG has been investigated.

In 1992, the International Fuel Cells Corporation was awarded a contract by EPA to conduct a 1-year demonstration of the application of a commercially available fuel cell (i.e., phosphoric acid) to LFG. Initial stages of this research focused on gas cleanup issues. The field-demonstration phase of the project was initiated in the fall of 1994. The major technical issue with its application to LFG is gas cleanup. The system that was developed for the full-scale demonstration uses an adsorber for hydrogen sulfide, dehydration (to condense water and hydrocarbons), desiccant (to adsorb any remaining water), low-temperature condenser (to remove any remaining halogenated compounds), and activated carbon. As of May 1997, the gas cleanup system had been operated 5,411 hours on landfill gas. The amount of time that the gas cleanup system and fuel cell have been operated on a full-scale basis is in excess of 4,000 hours. The demonstration was initially located in California and then moved to a site in New England. The final report for the California demonstration project is available (*Demonstration of Fuel Cells to Recover Energy From Landfill Gas*, Trociolla and Preston, 1998) along with a number of other publications (Sandelli, 1992; Sandelli and Spiegel, 1992; Sandelli et al., 1994).

Efforts are underway to make the fuel cell technology economically feasible before the turn of the century. Federal programs through the U.S. Department of Energy and other efforts are directed to help make fuel cells economical due to their environmental advantages. Fuel cells are currently widely used for natural gas applications. Their use for landfill gas and other waste methane sources such as anaerobic digesters at wastewater treatment facilities is a new application of this technology. Several sites around the U.S. are in various stages of planning to begin projects using PAFCs. Other types of fuel cells (e.g., molten carbonate) are also being investigated for fuel cell applications, but currently the only commercially available fuel cell is the PAFC. We will continue to track their performance and penetration into the market place.

Another emerging technology for landfill gas applications is the conversion of landfill gas to vehicle fuel. A major advantage with converting LFG to vehicle fuel is that it produces significantly lower emissions relative to gasoline and diesel fuels. Although several projects have been proposed and operated temporarily in the U.S., the Sanitation Districts of Los Angeles County (Districts) have been the most successful in operating a CLG plant. This plant, located at the Puente Hills landfill, has been in operation since 1993 (Wheless et al., 1996). This project uses a membrane technology to convert LFG to vehicle fuel. The station has a design capacity equivalent to 3,800 liters of gasoline (1,000 gallons) per day. The Districts utilize the CLG to run a fleet of 13 vehicles, ranging from vans to large on-road tractors. The Districts think that low CNG prices and design problems with early models of CNG truck engines have slowed the adoption of this technology, and newer CNG engine designs, including dual fuel models, may provide the fuel demand.

Another successful application of converting LFG to vehicle fuel is by the SITA Group (Paris, France), an international waste management company. As reported by M. Balbo, 1997, this pilot program has a number of advantages including its relatively simple design which reduces the cost. The project is located in Sonzay, France, and has been operating since 1994. The LFG is compressed to 14 bars pressure by a two-stage compressor and then cooled by a heat exchanger. The LFG is then injected into a scrubbing tower where the countercurrent water flow scrubs the gases (removing carbon dioxide and hydrogen sulfide) and the methane gas is then dried using an adsorbent. The clean and dry gas is then compressed to 250 bars (200 pounds/square inch) pressure and then stored. The city of Tours converted a fleet of 30 small cars with the capacity to operate on either the CLG produced by the landfill or diesel fuel. This pilot project has been so successful that SITA plans to scale it up to supply fuel to 60 city buses.

Leachate and LFG condensate collection and treatment can be expensive depending upon regulatory requirements. LFG can be used to evaporate liquids and combust the organics. The principle of leachate evaporation systems (LESs) is simple and direct: use LFG collected at the site as an energy source to evaporate water and combust the organic compounds in the leachate. Depending on local requirements, the highly concentrated (hence reduced volume) effluent is returned to the landfill or shipped off-site for disposal. The process concentrates and precipitates metals, primarily as salts, while stripping organics to a thermal oxidizer (e.g., flare) or RIC engine for destruction.

There are several variations of leachate evaporator systems. They differ only in the methods used to transfer heat to leachate and treatment of the exhaust vapor. One commercial design theme simply destroys the leachate vapors and LFG not consumed in the evaporation process in a slightly modified enclosed flare [Organic Waste Technologies, Inc. (OWT)]. Another variation combusts the evaporated vapors and LFG in an RIC engine to produce electricity. Here, the waste heat from the engine aids in evaporating the leachate (Power Strategies L.L.C.).

These LES technologies are expected to be relatively commonplace in the future, as leachate treatment on site is required or found to be more cost-effective. The first known demonstration of this technology is by Omni-Gen in conjunction with Balkema Bros. at the Orchard Hill Landfill in Michigan in 1992. Several commercial leachate evaporators are on order. Developers of this technology are very optimistic and anticipate 10 or more of these projects in full-scale operation by the end of 1998.

TECHNOLOGIES FOR LANDFILL GAS UNDER RESEARCH & DEVELOPMENT (TIER 2)

Tier 2 technologies are currently undergoing research and development and have been demonstrated either at the bench- or field-scale. Included in this group are:

- Operation of landfills as either anaerobic or aerobic bioreactors;
- Production of methanol from LFG;
- Production of commercial carbon dioxide (CO_2) from LFG; and
- Use of LFG for heating and CO_2 enhancement in greenhouses.

Operating landfills as either anaerobic or aerobic bioreactors are similar in that the objectives are to increase the rate of waste biodegradation by enhancing the environmental conditions conducive to microbial activity (e.g., moisture, pH). The primary difference of the two technologies is that, in anaerobic bioreactors, the objective is to enhance the generation of methane; whereas, in aerobic reactors, the objective is to minimize methane generation. Both methods utilize leachate recirculation as a means to control and enhance moisture levels within the landfill. Leachate recirculation has been performed for a number or years primarily as a means to economically manage the leachate. However, it is not usually allowed unless the composite liner, required by Subtitle D of the Resource Conservation and Recovery Act, is in place. Although, this is an option for new sites, it may not be an option for older sites.

Although the operation of landfills under enhanced anaerobic conditions has been under investigation for several decades, there are only a few pilot studies. California's Yolo County project is considered probably the best demonstration of this technology conducted to date in terms of the data and information being collected. Detailed information on this project is provided along with information on some recent studies looking at the operation of landfills under aerobic conditions. (Roe et al, 1998).

Conversion of LFG to methanol for use as a vehicle fuel or as a chemical feedstock has been investigated in the U.S. since the early 1980s. To date, there has not been a field demonstration of this technology. Early investigations of this technology concluded that it was technically feasible; however, only marginal economic returns were expected with the pricing of methanol during that time (International Harvester Company, 1982; Science Applications, Inc., 1983). However, during the early 1990s, the price of methanol increased substantially (2 to 3 times) due to reformulated gasoline (RFG) requirements of the Clean Air Act Amendments of 1990. Methanol and its derivative, methyl butyl ether (MTBE), are prime candidates for use as oxygenates in RFG. MTBE is currently being used in many RFG formulations in U.S. ozone nonattainment areas. Consequently, the interest in converting landfill gas to methanol resurfaced in this past decade.

The production of commercial-grade CO_2 from LFG is also under research and development. Most LFG utilization technologies do not attempt to capture the CO_2 component of LFG for commercial use. Hence, the commercial value and associated environmental benefits are not realized from these projects. The feasibility of producing commercial-grade CO_2 was studied by Acrion Technologies, Inc. This study, funded by the U.S. Department of Energy, indicated an increasing demand for high purity (food grade) liquid CO_2 (Acrion, 1992). In 1992, domestic sales were estimated to be ~11,000 tons per day, and the historical growth rate was cited as 8%. Retail prices for high purity liquid CO_2 were stated to be between \$50 and \$200 per ton depending on the volume and delivery point (transportation is the key driver of cost for CO_2). U.S. landfills were estimated to be able to supply twice the current CO_2 demand.

Current utilization technologies do not attempt to recover LFG CO_2 because: (1) recovery would require recompression of the CO_2 which can be expensive; (2) trace contaminant removal to the purity requirements for food grade CO_2, cannot be performed by a single commercial process (Acrion, 1992); and (3) non-technical hurdles, such as the public's perception of a food product developed from LFG.

Acrion has been developing a LFG cleaning technology to produce high-purity liquid CO_2 and fuel-grade methane from raw LFG. The purification system underwent bench-scale testing in 1994, and a full-scale field demonstration is planned for the fall of 1998. This technology offers a unique opportunity for controlling both methane and CO_2 from LFG to produce commercial products. However, information on the capital and operating costs for this process was not available.

The process developed by Acrion simultaneously recovers fuel grade methane and CO_2 from raw LFG. Acrion estimated that over 98% of the methane in the LFG is recovered by the process. Approximately 15% of the recovered methane is consumed by engines to generate on-site power. About 70% of the LFG CO_2 is recovered as product. Most of the balance is lost in the fuel to the engines and as contaminated liquid absorbent that is incinerated in the on-site flare. The CO_2 product is estimated to contain approximately 1.5 parts per million by volume (ppmv) of total impurities (Acrion, 1992).

Acrion is also investigating a process that uses cold liquid CO_2 from the LFG to purify both the CH_4 and CO_2 product streams (Brown, 1997). Contaminants are concentrated in a separate stream of CO_2 that is fed to an on-site flare. According to Acrion, negotiations are nearing completion for a demonstration project at a site in the State of New York.

POTENTIALLY APPLICABLE TECHNOLOGIES (TIER 3)

Tier 3 technologies may have applicability to LFG utilization or management based on applications with similar fuel types (e.g., natural gas). Technologies that are considered as potentially applicable for LFG-E conversion include the Stirling engine, Organic Rankine cycle (ORC), and molten carbonate fuel cells. The first two technologies potentially could use waste heat from flares used to control LFG to generate mechanical energy. However, on each of these technologies, there is limited data and information on which to evaluate their potential technical and economical feasibility to LFG applications.

In the Stirling engine, power is generated by compressing cool gas (working fuel) and expanding it when hot, a process common to most heat engines. Extensive research has been devoted to the development of Stirling engines for space power systems (using solar energy) and for use in automobiles. Currently, Stirling engines are not commercially available but several manufacturers hope to develop commercial units for industrial and automobile use. However, most research is focused on small-sized engines, from less than 2.5 kW to about 100kW; therefore, it may be cost prohibitive to employ for a typical LFG-E project.

The ORC is a process that uses an organic fluid (rather than steam) in a closed cycle to convert thermal energy into mechanical energy. The advantages of an ORC over a steam Rankine cycle include: (1) Depending on the type and boiling point of the organic fluid chosen, the organic fluid will completely vaporize at a much lower temperature and pressure than steam, thus eliminating steam system problems (like turbine blade erosion caused by entrainment) and the need for an economizer, superheater, or boiler drum; (2) organic working fluid is non-corrosive; and (3) the ORC is a closed system which eliminates the need to continuously add fluid or pre-treat the fluid.

Perennial Energy, Inc. (PEI) of West Plains, Missouri, has developed a commercially available ORC that uses waste heat from a flare, thermal oxidizer, or other combustor as a heat source (PEI, 1993). The ORC is currently being used to generate electricity using geothermal power at a plant site operated by Pacific Energy in Mammoth, California. However, no current usage of an ORC in a LFG application has been identified.

Molten carbonate fuel cells (MCFCs) use an electrolyte of lithium and potassium carbonate and operate at temperatures of approximately 650 °C (1200 °F) compared to PAFCs which operate at about 200 °C (390 °F) (DOE, 1997). The higher operating temperature of MCFCs creates a potential for higher system efficiencies (around 70%), if this heat can be utilized (e.g., in a cogeneration system). Application of this technology is in the very early stages.

DOE and EPRI are sponsoring a project to demonstrate use of an MCFC on LFG. An LFG cleanup system was successfully demonstrated at the Anoka Landfill in Minnesota (Roe et al., 1998). A laboratory demonstration (using synthetic LFG) was recently completed; however, data are not yet available. Project proponents state that MCFCs look particularly promising for LFG application due to their good tolerance of CO_2.

While some landfills can generate large quantities of gaseous pollutants, most generate only small amounts sufficient to support comparatively small power generation projects (300 to 1,000 kW). Traditional energy utilization technologies may not be cost-effective alternatives for conversion of LFG into useable energy at these small landfills, or may be difficult to permit due to their significant NO_x, carbon monoxide, and other combustion byproduct emissions (e.g., RIC engines). For landfills already using (permitted) flares for controlling LFG emissions, it may not be desirable to eliminate this type of control, but rather retrofit utilization equipment in order to take advantage of waste heat. In both of these situations, the Stirling engine and/or ORC may have potential applicability.

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REFERENCES

61 FR 49, 1996. Federal Register, U.S. Environmental Protection Agency, "Standards of Performance for New Stationary Sources and Guidelines for Controls of Existing Sources, Municipal Solid Waste Landfills," Final Rule and Guidelines, pp. 9905-9944, March 12, 1996.

Acrion, 1992. Landfill Gas Recovery for Compressed Natural Gas Vehicles and Food Grade Carbon Dioxide, SBIR Phase I Final Report, prepared for U.S. Department of Energy. Morgantown Energy Technical Center, Contract No. DE-FG02-91ER81223. May 20, 1992.

Arthur D.Little, Inc. The Role of Fuel Cell Technology in the International Power Equipment Market - Policy/Strategy Issues. Prepared for the World Fuel Cell Council, Frankfurt, Germany. Arthur D. Little, Inc., 1993.

Augenstein, D. and Pacey, J., 1992. Landfill Gas Energy Utilization: Technology Options and Case Studies. EPA-600/R-92-116 (NTIS PB92-203116), June 1992.

Balbo, M., Appointment in Sonzay: Landfill Gas Fueled Vehicles, *Waste Age*, May 1997.

Brown, W., Acrion Technologies, Inc., personal communication with S. Roe, E. H. Pechan & Associates, Inc., September 1997.

DOE, 1997. U.S. Department of Energy, Information on fuel cell technology down-loaded from the Federal Energy Technology Center Web Site (www.metc.doe.gov/research.power/fc.html), May 5, 1997.

Doorn, M., Pacey, J., and Augenstein, D. 1995, Landfill Gas Energy Utilization Experience: Discussion of Technical and Non-Technical Issues, Solutions, and Trends. EPA-600/R-95-035 (NTIS PB95-188108).

IHC (International Harvester Co.). 1982. Methanol from Landfill Gas Technology and Economics. Prepared for the New York State Energy Research and Development Authority, Albany, NY. PB83-169144, December 1982.

PEI (Perennial Energy, Inc.). 1993. Organic Rankine Cycle System. West Plains, MO.

Roe, S., Reisman, J., Strait, R., and Doorn, M. Emerging Technologies for the Management and Utilization of Landfill Gas. EPA-600/R-98-021, February 1998.

Roe, S., Fields, P.G., and Coad, R.E., 1995. Methodologies for Quantifying Pollution Prevention Benefits from Landfill Gas Control and Utilization. EPA-600/R-95-089 (NTIS PB95-243176).

Roqueta, A. Presentation at the 20th Annual Landfill Gas Symposium, Monterey 25 – 27, 1997. Published in the Proceedings of the SWANA's 20th Annual Landfill Gas Symposium.

Sandelli, G.J. 1992. Demonstration of Fuel Cells to Recover Energy from Landfill Gas: Phase I Final Report: Conceptual Study. EPA-600/R-92-007 (NTIS PB92-137520).

Sandelli, G.J. and Spiegel, R.J. 1992. Fuel Cell Energy Recovery from Landfill Gas. *Journal of Power Sources,* 37, (1992) 255-264.

Sandelli, G.J., Trocciola, J.C., and Spiegel, R.G. 1994. Landfill Gas Pretreatment for Fuel Cell Applications. *Journal of Power Sources,* 49, (1994) 143-149.

Science Applications, Inc. 1983. Methanol Production from Indigenous Resources in New York State. Volume 1. Executive Summary. Prepared for the New York State Energy Research and Development Authority, Albany, NY. PB87-110540, May 1983.

Thorneloe, S.A. 1992. Landfill Gas Recovery/Utilization-Options and Economics. Presented at the Institute of Gas Technology's Sixteenth Annual Conference on Energy from Biomass and Wastes. Orlando, FL. March 5, 1992.

Trociolla, J.C. and Preston, J.L.1998. Demonstration of Fuel Cells to Recover Energy From Landfill Gas, Phase III. Demonstration Tests, and Phase IV. Guidelines and Recommendations. Vol. 1. Technical Report, EPA-600/R-98-002a.

U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Compilation of Air Pollutant Emissions Factors, AP-42, Volume 1, 5th Edition, GPO 055-000-005-001, January 1995.

U. S. Environmental Protection Agency, Office Of Research and Development, Environmental Technology Verification Program – Verification Strategy, EPA/600/K-96/003 (NTIS PB97-160006), February 1997.

Wheless, E., Cosulich, J., and Wang, A. 1996. Converting Landfill Gas to Vehicle Fuel: The Results of Over 30 Months of Operation, Published in Proceedings of the 19th Annual Landfill Gas Symposium, March 1996, Raleigh, NC.

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16. ABSTRACT The paper summarizes an EPA report describing the "next generation" of technologies for landfill gas (LFG) control and utilization. (NOTE: EPA's Office of Research and Development is responsible for evaluating the next generation of technologies for reducing greenhouse gas (GHG) emissions. The recently published report gave results of a review of the next generation or emerging technologies for LFG control and utilization.) EPA's Environmental Technology Verification (ETV) program has been launched. Through this program, technology purchasers can access an objective source of data to make informed purchasing decisions. In addition, vendors who want to market their products on a "level playing field" will have objective credible data through ETV. As part of ETV, EPA has formed a center for the verification of technologies that reduce GHG emissions. What is ETV and what does it mean to LFG? The paper provides the answers and points to further information on the program.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Verifying	Stationary Sources	14B
Earth Fills	Landfill Gas	13C
Gases	Environmental Technology Verification (ETV)	07D
Emission		14G
Greenhouse Effect		14A

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