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Air and Energy Engineering
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Project Summary

Demonstration of Fuel Cells to Recover Energy from Landfill Gas: Phase I Final Report: Conceptual Study

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International Fuel Cells Corporation is conducting a U.S. EPA-sponsored program to demonstrate energy recovery from landfill gas using a commercial phosphoric acid fuel cell power plant. The U.S. EPA is interested in fuel cells for this application because it is potentially one of the cleanest energy conversion technologies available. The report discusses the results of Phase I, a conceptual design, cost, and evaluation study. The conceptual design of the fuel cell energy recovery concept is described and its economic and environmental feasibility is projected. A preliminary design of the project demonstration was established from the commercial concept. It addresses the key demonstration issues facing commercialization of the concept. Candidate demonstration sites were evaluated, which led to selection and EPA approval of the demonstration site.

A plan for Phase II activities is discussed. Phase II will include construction and testing of a landfill gas pretreatment system which will render landfill gas suitable for use in the fuel cell. Phase III will be demonstration of the energy recovery concept.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The U.S. Environmental Protection Agency (EPA) has proposed standards and guidelines for the control of air emissions from municipal solid waste landfills. Although not directly controlled under the proposal, the collection and disposal of waste methane, a significant contributor to the greenhouse effect, would result from the emission regulations. This EPA action will provide an opportunity for energy recovery from the waste methane that could further benefit the environment. Energy produced from landfill gas could offset the use of foreign oil, and air emissions affecting global warming, acid rain, and other health and environmental issues.

International Fuel Cells Corporation (IFC) was awarded a contract by the U.S. EPA to demonstrate energy recovery from landfill gas using a commercial phosphoric acid fuel cell. IFC is conducting a three-phase program to show that fuel cell energy recovery is economically and environmentally feasible in commercial operation. Work was initiated in January 1991. The project report discusses the results of Phase I, a conceptual design, cost, and evaluation study, which addressed the problems associated with landfill gas as the feedstock for fuel cell operation.

Phase II of the program includes construction and testing of the landfill gas pretreatment module to be used in the demonstration. Its objective will be to determine the effectiveness of the pretreatment system design to remove critical fuel cell catalyst poisons such as sulfur and halides. A challenge test is planned to show the feasibility of using the pretreatment process at any landfill in conjunction with the fuel cell energy recovery concept. A preliminary description of the gas pretreater is presented.

Phase III of the program will be demonstration of the fuel cell energy recovery concept. The demonstrator will operate at Penrose Station, an existing landfill gas-to-energy facility owned by Pacific Energy in Sun Valley, California. Penrose Station is an 8.9 MW internal combustion engine facility supplied with landfill gas from four landfills. The electricity produced by the demonstration will be sold to the electric utility grid.

Phase II activities began in September 1991, and Phase III activities are scheduled to begin in January 1993.

Commercial Fuel Cell Landfill Gas to Energy System Conceptual Design

A commercial fuel cell landfill gas to energy system concept was designed to provide a modular, packaged, energy conversion system which can operate on landfill gases with a wide range of compositions as typically found in the United States. The complete system incorporates the landfill gas collection system, a fuel gas pretreatment system, and a fuel cell energy conversion system. In the fuel gas pretreatment system, the raw landfill gas is treated to remove contaminants to a level suitable for the fuel cell energy conversion system. The fuel cell energy conversion system converts the treated gas to electricity and useful heat.

Landfill gas collection systems are presently in use in over 100 landfills in the United States. These systems have been proven effective for the collection of landfill gas. Therefore these design and evaluation studies were focused on the energy conversion concept.

Overall System Description

The commercial landfill gas to energy conversion system is illustrated in Figure 1. The fuel pretreatment system has provisions for handling a wide range of gas contaminants. Multiple pretreatment modules can be used to accommodate a wide range of landfill sizes. The wells and collection system collect the raw landfill gas and deliver it at approximately ambient pressure to the gas pretreatment system. In the gas pretreatment system the gas is treated to remove non-methane organic compounds (NMOCs) including trace constituents which contain halogen and sulfur compounds.

The commercial energy conversion system shown in Figure 1 consists of four fuel cell power plants. These power plants are designed to provide 200 kW output when operating on landfill gas with a heating value of 500 Btu/scf.* The output from the fuel cell is utility grade ac electric power. It can be transformed and put into the electric grid, used directly at nearby facilities, or used at the landfill itself. The power plants are capable of recovering cogeneration heat for nearby use or rejecting it to air.

* 1 Btu/scf = 37.3 kJ/sm³

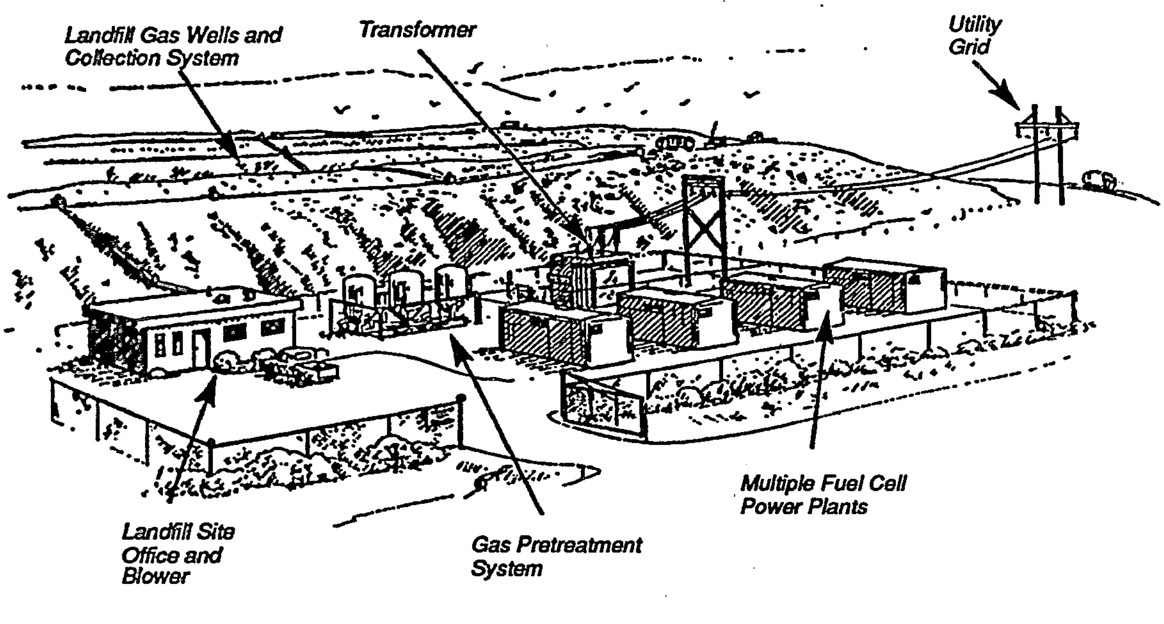

Figure 1. Fuel cell energy recovery commercial concept.

As configured in Figure 1, the commercial system can process approximately 18,000 scf/h* of landfill gas (mitigate 9050 scf/h of methane) with minimum environmental impact in terms of liquids, solids, or air pollution.

Fuel Pretreatment System

The fuel pretreatment system incorporates two stages of refrigeration combined with three regenerable adsorbent steps. The use of staged refrigeration provides tolerance to varying landfill gas constituents. The first stage significantly reduces the water content and removes the bulk of the heavier hydrocarbons from the landfill gas. This step provides flexibility to accommodate varying landfill characteristics by delivering a relatively narrow cut of hydrocarbons for the downstream beds in the pretreatment system. The second refrigeration step removes additional hydrocarbons by a proprietary process and enhances the effectiveness of the activated carbon and molecular sieve beds, which remove the remaining volatile organic compounds and hydrogen sulfide in the landfill gas. This approach is more flexible than utilizing dry bed adsorbents alone and has built-in flexibility for the wide range of contaminant concentrations which can exist from site to site and even within a single site varying with time.

The three adsorbents are regenerated by using heated gas from the process stream. A small portion of the treated landfill gas is heated and then passes through the beds to strip the adsorbed contaminants. After exiting the final bed, the regeneration gas is fed into a low nitrogen oxide (NO_x) incinerator where it is combined with the vaporized condensates from the refrigeration processes, and the mixture is combusted to provide 98% destruction of the NMOCs from the raw landfill gas.

The pretreatment system design provides flexibility for operation on a wide range of landfill gas compositions: it has minimal solid wastes, high thermal efficiency, and low parasite power requirements. The pretreatment system is based upon modification of an existing system and utilizes commercially available components. The process train and operating characteristics need to be validated by demonstration. Key demonstrations in Phase II will include: the achievement of low total halide contaminant levels in the treated gas; effectiveness of the regeneration cycle as affected by regeneration time and temperature; durability of the regenerable beds; and low environmental emissions.

* 1 scf/h = 0.028 sm³/h

Fuel Cell Power Plant

The commercial landfill gas energy conversion conceptual design incorporates four 200-kW fuel cell power units. Since each of the four units in the concept is identical, this discussion will focus on the design issues for a single 200-kW power unit.

A preliminary design of a fuel cell power plant was established to identify the design requirements which allow optimum operation on landfill gas. Three issues specific to landfill gas operation were identified which reflect a departure from a design optimized for operation on natural gas. A primary issue is to protect the fuel cell from sulfur and halide compounds not scrubbed from the gas in the fuel pretreatment system. An absorbent bed was incorporated into the fuel cell fuel preprocessor design which contains both sulfur and halide absorbent catalysts. A second issue is to provide mechanical components in the reactant gas supply systems to accommodate the larger flow rates that result from use of dilute methane fuel. The third issue is an increase in the heat rate of the power plant by approximately 10% above that anticipated from operation on natural gas. This is a result of the inefficiency of using the dilute methane fuel. The inefficiency results in an increase in heat recoverable from the power plant. Because the effective fuel cost is relatively low, this decrease in power plant efficiency will not have a significant impact on the overall power plant economics.

The landfill gas power plant design provides a packaged, truck transportable, self-contained fuel cell power plant with a continuous electrical rating of 200 kW. It is designed for automatic, unattended operation, and can be remotely monitored. It can power electrical loads either in parallel with the utility grid or isolated from the grid.

Environmental and Economic Assessment of the Fuel Cell Energy Conversion System

The commercial application of the concept to the market described previously was assessed. For the purpose of the evaluation, a site capable of supporting four fuel cell power modules was selected. The site would produce approximately 434,000 scf of landfill gas per day. The gas contains approximately 50% methane with a heating value of 500 Btu/scf.

The analysis of the environmental impact shows that both the fuel cell and a flare system can be designed to eliminate the methane and the non-methane organic compounds from the landfill gas system. For the example site considered, the methane elimination is essentially complete for both systems, and 98% of the NMOCs are destroyed. Trace amounts of sulfur oxides (SO_x) and NO_x will be emitted in each case. With the fuel cell system, however, significant reductions of NO_x and SO_x will be achieved due to the fuel cell energy generation. This analysis assumes an 80% capacity factor for the fuel cell and offsetting emissions from electric utility power generation using a coal-fired plant meeting New Source Performance Standards. For the example site, the fuel cell energy conversion system provides 5.6 million kWhr of electricity per year, with a net reduction of 35.2 tons* per year of NO_x and 16.8 tons per year of SO_x from reduced coal use.

Economically the fuel cell energy system has the potential for deriving revenues from electric sales, thermal sales, and emission offsets credits. These revenues can be used to offset the investment cost associated with gas collection, gas pretreatment, and fuel cell power units. The level of these revenues depends upon the value of the electricity, the amount and value of the heat used, and the value of the emissions offsets.

The fuel cell energy conversion system was studied to establish the net revenues or costs for processing landfill gas to mitigate methane emissions. For this analysis, it was assumed that the fuel cell energy conversion system and the flare system would have an overall annual capacity factor of 80%. For this analysis, two levels of fuel cell installed costs were considered. The lower level represents a fully mature cost when the power plant has been accepted into the marketplace, and is routinely produced in large quantities. The upper level represents a price level when the power plant is being introduced into the marketplace, and is produced on a moderate and continuous basis.

Figure 2 shows the fuel cell revenues for the most stringent application situation (no emission credits or thermal energy utilization). In this case, the fuel cell receives revenues only from the sale of electricity. Although the emissions are lower from the fuel cell, no specific credit or value is attached to them for this example. Under these conditions the fuel cell is still the economic choice for most locations at the mature product installed cost. At the entry level cost the fuel cell is economical in those areas where the value of electric-

* 1 ton = 907 kg

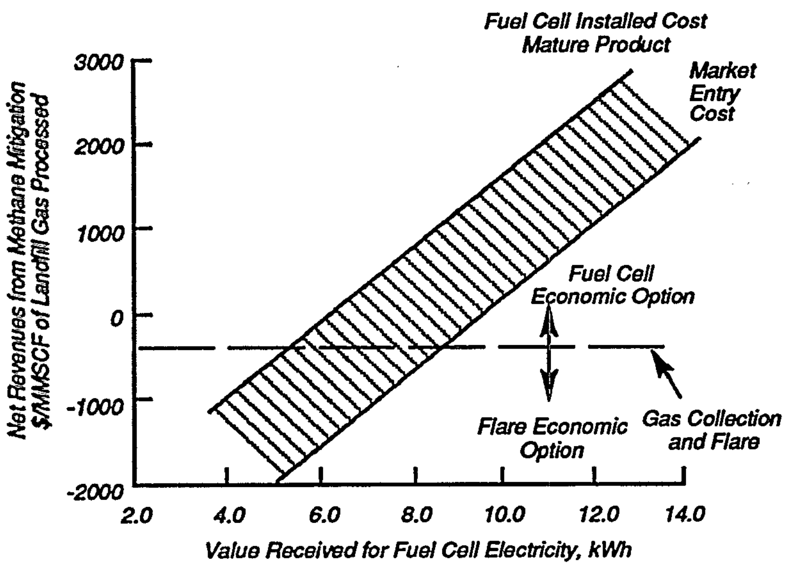

Figure 2. Comparison of fuel cell to flare for methane mitigation assuming electric revenues only.

ity is 9 cents per kWh or higher. With the potential for revenue from thermal energy or emission offset credits, the economics become more competitive. Thus the applicability of the concept would become attractive to a broader market.

Other energy conversion systems could also produce electric and/or thermal energy. Both the internal combustion engine and the gas turbine engine have been suggested as options for methane mitigation at landfill sites. For the landfill size selected for this analysis, the internal combustion engine is more effective than the gas turbine options for cleanup. This is used as the basis for the comparisons provided here. The internal combustion engine can provide both heat and electric energy while consuming the methane at the landfill gas site. With the present state-of-the-art technology, however, a lean-burn internal combustion engine has higher levels of NO_x emissions than the fuel cell unless special precautions are taken to clean the exhaust. For this analysis two cases were considered. The first case assumes no cleanup of the internal combustion engine exhaust, and the second assumes that the exhaust is cleaned with selective catalytic reduction (SCR). Since the SCR employs a catalyst in the cleanup system, the landfill gas will have to be pretreated in a manner similar to the fuel cell system. For those cases with a SCR cleanup system, a pretreatment system has also been included as part of the total system cost.

Figure 3 shows the results of the economic analysis for the fuel cell system and the internal combustion engine system. Since both systems can provide electricity, the comparison between the systems is based on the cost of electricity generated from the energy conversion system with appropriate credit for thermal sales and/or emission offsets. The fuel cell is competitive at the full mature price when no exhaust cleanup is required with the internal combustion engines. However, the operation of the internal combustion engine at the landfill site would be quite dirty, and significant amounts of NO_x would be added to the ambient air compared to the fuel cell. For many locations where the fuel cell would be considered, such as California or other high emissions areas, the exhaust cleanup option is required. Consequently, the fuel cell option would be fully competitive with the internal combustion engine option for most cases where on-site cleanup of the internal combustion engine is required. In areas where a SCR would be employed to clean up an internal combustion engine exhaust, the fuel cell concept is competitive at entry level cost.

Based on the analysis of both the flare option and other energy conversion options, the fuel cell power plant is fully competitive in all situations in the mature production situation. For initial power plant applications with limited lot production, the fuel cell power plant is competitive in areas with high electric rates and/or severe emissions restrictions at the local landfill site.

Demonstration Project Preliminary Design

The objective of the demonstration project is to validate the economic and environmental feasibility of a commercial fuel cell energy recovery concept operating on landfill gas. A preliminary design of the demonstration project shown in Figure 4 is described, which identifies the key issues to be resolved before demonstrations and describes the major components of the demonstration project.

Demonstration project design requirements were derived from the commercial concept. These requirements were used to define project site selection criteria, gas pretreatment system design, and commercial fuel cell modifications to accommodate landfill gas.

The site selected for the demonstration project is the Penrose Station in Sun Valley, California. This site, owned and operated by Pacific Energy, accepts landfill gas from four municipal sold waste landfills. Penrose Station presently produces 8.9 MW of electricity from landfill gas, using internal combustion engines. The demonstration will operate on a slip stream from Penrose's gas feed.

Because Penrose accepts gas from four fills, some of which contain industrial waste, the composition and contaminant levels vary considerably. Average methane content is 44% and the gas typically contains 150 ppm_v sulfur and 78 to 95 ppm_v halides. The sulfur contaminant levels are higher than typically found in municipal solid waste landfill gas. A successful demonstration at Penrose will show applicability of the concept to a broad segment of the market.

Conclusions

Based on the environmental and economic evaluation of the commercial fuel cell energy system, the following can be concluded:

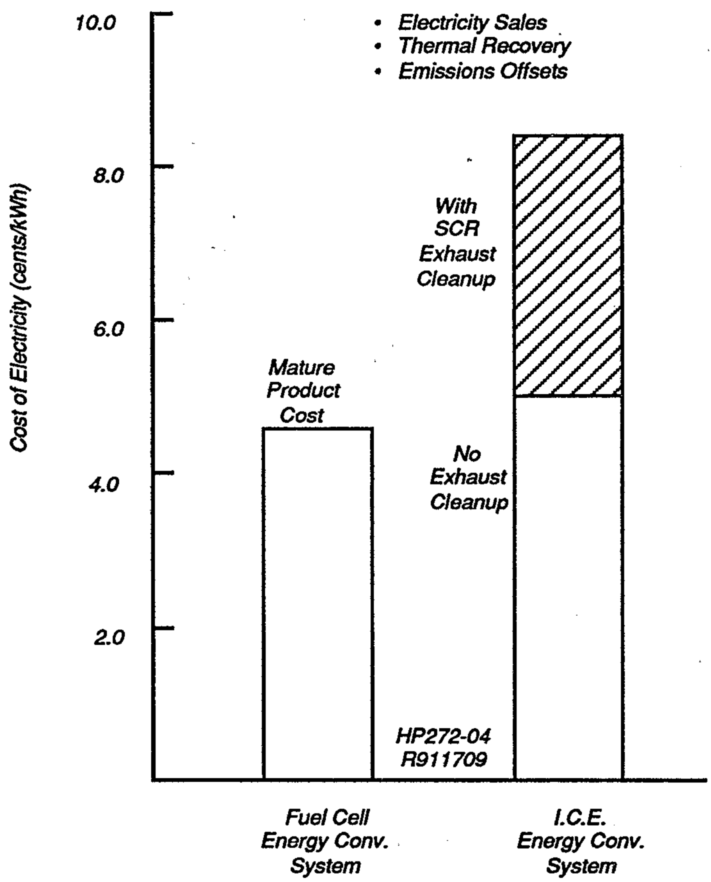

Figure 3. *Comparison of fuel cell to internal combustion engine energy conversion system.*

- The fuel cell landfill gas to energy conversion system provides a net reduction in total emissions while simultaneously mitigating the methane from the landfill gas.
- Fuel cells will be competitive at initial product prices on landfill sites located in high electric cost areas or where the thermal energy can be utilized. The fuel cell will also be attractive where there is a credit for the environmental impact of fuel cell energy conversion.
- When the projected mature product price is achieved, fuel cells will be competitive for most application scenarios. In many situations, fuel cells will provide net revenues to the landfill owners. This could, in the long term, result in methane mitigation without additional cost to the ultimate consumer.
- A demonstration project design was established which addresses the key technical issues facing commercial application of the fuel cell energy recovery concept to the market. A site has been selected for the demonstration which fairly represents the landfill gas market.

Recommendations

Phase II of the project, which evaluates the gas pretreatment system at the selected site, should be conducted to verify that landfill gas can be cleaned to meet fuel cell requirements. The pretreatment system design needs to be finalized to resolve the remaining cleanup issues and construction started as soon as possible in Phase II. A challenge test should be defined to evaluate the limits of operating capability of the pretreatment system including regeneration and adsorption breakthrough conditions.

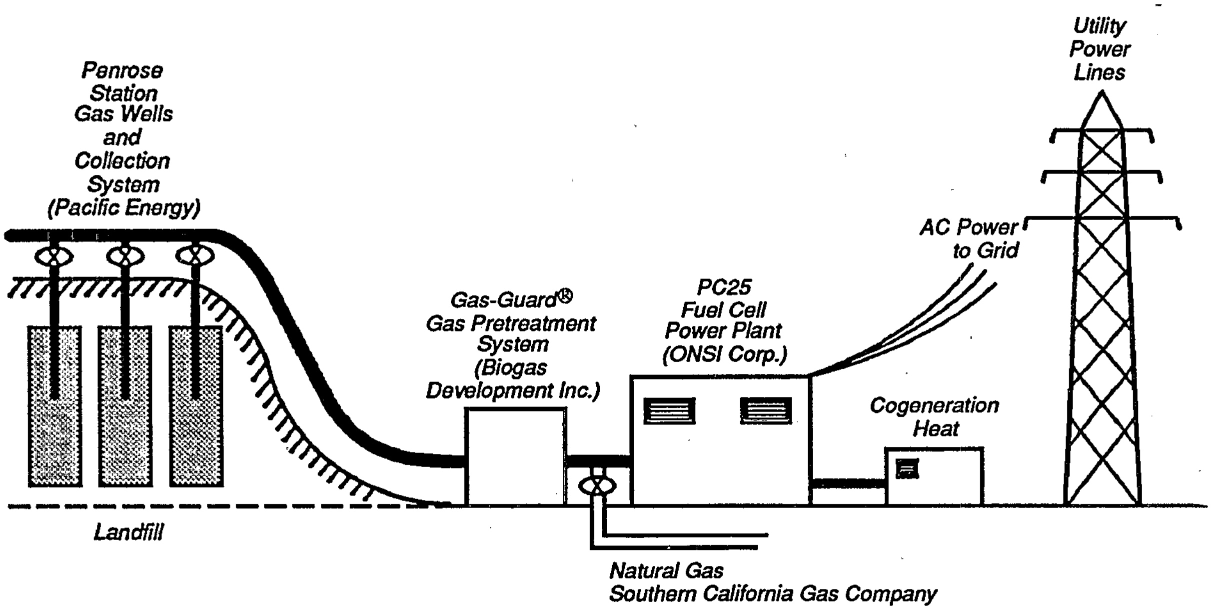

Figure 4. *Proposed demonstrator concept.*

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The complete report, entitled "Demonstration of Fuel Cells to Recover Energy from Landfill Gas: Phase I Final Report: Conceptual Study," (Order No. PB92-137520/AS; Cost: $19.00, subject to change) will be available only from:
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