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Project Summary

Demonstration of Fuel Cells to Recover Energy from an Anaerobic Digester Gas—Phase I. Conceptual Design, Preliminary Cost, and Evaluation Study

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This document summarizes Phase I of a study to demonstrate the recovery of energy from waste methane produced by anaerobic digestion of waste water treatment sludge. The U.S. Environmental Protection Agency (EPA) is interested in the fuel cell for this application because it is potentially one of the cleanest energy technologies available. This program is focused on using a commercial phosphoric acid fuel cell power plant because of its inherently high fuel efficiency, low emissions characteristics, and high state of development. The environmental impact of widespread use of this concept would be a significant reduction in global warming and acid rain air emissions.

Phase I is a conceptual design, preliminary cost, and evaluation study. The conceptual design of the fuel cell energy system is described and its economic and environmental feasibility is projected. Technology evaluations aimed at improving the phosphoric acid power plant operation on Anaerobic Digester Gas (ADG) are described and the two optional programs for completing the project are described. In Option I, the technical issues of ADG contaminant removal and improved, fuel cell power plant performance on low-Btu fuel are addressed. In Option II, a one-year field performance evaluation of the energy recovery concept is planned. The demonstration will document the environmental and economic feasibility of the fuel cell 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

International Fuel Cells Corporation (IFC) is conducting a three-phase program to determine if a fuel cell, which utilizes the methane (CH_4) from a wastewater treatment (WWT) plant, is economically feasible and environmentally beneficial in commercial operation. This summary includes Phase I results of the program

CH_4 has been identified as a gas that may contribute to global warming. Recent information indicates that it is second only to global carbon dioxide (CO_2) in its contribution to radiative forcing. Worldwide, many sources of CH_4 emitted into the atmosphere include landfills, wastewater/sewage treatment plants, coal mines, and livestock waste. In the U.S., CH_4 produced in treatment plants is usually flared and sometimes utilized for in-plant uses, although plants that employ lagoon digesters frequently vent their gas. If the CH_4 emitted at facilities were converted to electricity, rather than being flared or used thermally, the amount of electricity generated at central electric utility plants could be reduced, thereby lowering emissions of CO_2, another global warming gas.

Fuel Cell Benefits

The CH_4 from WWT can be used thermally or can be converted to electricity using other technologies. However, conversion using a fuel cell offers several advantages:

- The fuel cell emits very few pollutants compared to other natural-gas-fueled equipment (see Figure 1).
- It produces electricity at 40% efficiency and, with recovery of waste heat, thermal efficiencies up to 85% are possible.
- Fuel cell power plants can be economical in small ratings (200 kW). As a consequence, they can be added incrementally to accommodate increases in waste treatment plant capacity while maintaining efficiency and emissions benefits.

Utilizing IFC's computer model, a performance comparison has been made between the estimated performance characteristics of a fuel cell operating on natural gas and one operating on anaerobic digester gas (ADG). The estimate given in Table 1 indicates that the performance of the ADG fuel cell will be excellent and similar to the natural gas model.

Using the total potential market for WWT plants, an assessment was made of the reduction of pollutants and global warming gases that would result from the use of fuel cells. This is shown in Table 2. This reduction in pollutants results from the generation of electricity using a fuel cell at the WWT plant site, thereby reducing the amount of electricity and associated pollutants generated at an electric utility central station site. The bases for these emission reductions are discussed in the full report.

In addition to providing environmental benefits, the fuel cell can also provide economic benefits to the owner of a WWT plant. In evaluating these benefits, several application credits were identified that may be applicable to facilities that install on-site electrical generation equipment; utilizing fuel cell power plants tends to increase the value of these credits, including

- *Biomass Energy Credits*—The Energy Policy Act of 1992 authorizes financial incentives of 1.5¢/kWh for power generated from biomass.
- *Emission Credits*—These credits could result if the fuel cell at the WWT facility displaced electricity that was otherwise generated using coal. The reduction in coal plant generation results in lowering the quantity of NO_x and SO_x emitted. This reduction in pollutants was valued at $1.10/kg. This value for SO_2 is consistent with guidelines established by the EPA for computing cost effectiveness of New Source Performance Standards. No guideline for NO_x has been established.
- *Backup Power Avoidance Credits*—WWT facilities typically utilize grid electricity plus backup diesels for critical loads. By using multiple 200-kW fuel cell modules to provide the facilities' power, it is estimated that 50% of the backup diesels can be eliminated, resulting in a savings of $500/kW of installed fuel cell power plant capacity.
- *Distributed Power Credit*—Fuel cell power plants have been identified by the Electric Power Research Institute and various utilities as a dispersed power generation technology that could mitigate the need to install, replace, or extend utility transmission and distribution power systems. It is estimated that the elimination of this need would save the utility approximately $500/kW of installed fuel cell capacity.

These credits may be grouped into various economic scenarios ranging from utilizing many of these credits (optimistic application) to utilizing few of the credits (pessimistic application). Table 3 summarizes the fuel cell economics for three scenarios using a cost for grid electricity of 5¢/kWhr, which is the U.S. average cost to large users. The details of each scenario are discussed in the full report. The data show that, for an "entry level" cost of the power plant of $3000/kW, the fuel cell is economic for the "moderate" and "optimistic" assumptions. For the mature fuel cell cost of $1500/kW, the fuel cell is economical for all the scenarios considered.

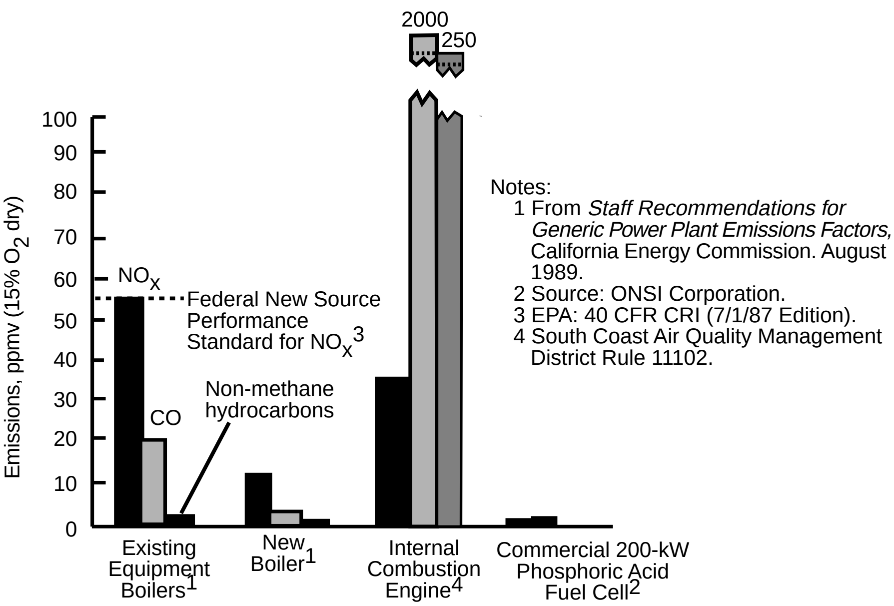

Figure 1. *Power plant emissions comparison (natural gas).*

Fuel Cell Operation on ADG

A number of WWT plants have been surveyed to determine the composition of their gas streams. The results of the gas analysis are shown in Table 4. The data indicate the ADG contains 55 to 65 vol % CH_4, and 30 to 40 vol % CO_2. The gas also contains hydrogen sulfide (H_2S) at the parts-per-million level.

The gas analysis for the various plants is based typically on a one-time analysis. The planned fuel cell demonstration portion of this program at the demonstration site will provide for periodic measurements of the impurity levels in order to assess their variabilities with time.

The commercial phosphoric acid fuel cell (PAFC) power plant has been designed to operate on natural gas, which is essentially CH_4. Since the CH_4 from an anaerobic digester is diluted with CO_2, a greater volume of gas must be ducted through the power plant to supply enough CH_4 to produce 200 kW of power. These higher flow rates result in higher pressure drops through the power plant. A steam-driven ejector pumps the fuel gas to the pressure required to overcome system pressure drops in the fuel cell power plant.

Table 1. *Estimated Performance Comparison for Nominal 200-Kw Output*

	Natural Gas Power Plant	ADG Power Plant
Fuel	Natural Gas	ADG
Electrical Efficiency (LHV), %	40	38
Heat Rate (HHV), kg.cal/kWhr	2,395	2,495
Available Heat, kg.cal/hr	190,000	200,000
Ambient Temperature for Fuel Water Recovery, °C	35	35
Start-up Fuel	Natural Gas	ADG

Table 2. *Reduction in Pollutants Through Use of Fuel Cells*

Global Warming Gases	Acid Rain and Health Related Gases		
CO_2, Mg/yr	NO_x, Mg/yr	SO_2, Mg/yr	CO, Mg/yr
4.59×10^6	15,181	22,983	1269

Table 3. *Fuel Cell Economics for ADG Applications*

Economic Assumptions	Fuel Cell Cost ($/kW)	
	1500	3000
Optimistic (Scenario "A")	LC*	LC
Moderate (Scenario "B")	LC	LC
Pessimistic (Scenario "C")	LC	EC**

* Cost of Electricity From Fuel Cell Lower Than Cost of Grid Electricity (@5¢/kWhr)
** Cost of Electricity From Fuel Cell Equal to Cost of Grid Electricity (@5¢/kWhr)

The fluid that provides the energy to pump the fuel gas is steam-generated by the fuel cell stack. In this program, testing of the ejector presently used in the fuel cell power plant confirmed that the steam produced by the stack is adequate to pump enough ADG to produce 200 kW.

A gas cleanup system has been designed to remove the H_2S which, if fed to the fuel cell, would degrade catalysts in the power plant. The design of this removal system is based on the use of a commercially available carbon-based material. The material has been tested at the laboratory level under this program and has been found to be very effective in removing H_2S. The material is believed to absorb sulfur by the Claus reaction:

$$H_2S + 1/2\ O_2 \rightarrow H_2O + S$$

In order to promote this reaction, low concentrations of oxygen are required in the gas stream. Testing of the carbon-based material on simulated ADG has shown that 0.3 vol % oxygen, consistent with the level at the Back River facility, is sufficient for high adsorbent capacity. Up to 50 wt % sulfur capacity was demonstrated in the laboratory testing.

Since this testing was performed in the laboratory on simulated ADG, a test at a WWT facility to verify the suitability of the gas cleanup approach is recommended. A schematic of the gas cleanup system for a fuel cell power plant is shown in Figure 2. In the design, provision is made for addition of air to the gas stream to provide additional oxygen, if required, to promote the Claus reaction.

This system is designed to accept a gas of variable inlet H_2S concentration. If the H_2S concentration is higher than the nominal level for that plant and the air concentration in the gas stream is lower than required, more air will be added. In addition, the exit concentration of H_2 from the system will be measured: if its concentration increases above the specified value due to exhausting the capacity of the bed, the bed will be replaced.

Site Recommendation for Fuel Cell Demonstration

Based on the favorable environmental and economic benefits of fuel cells at WWT plants and identification of a suitable gas cleanup system, a demonstration of the technology at a plant would be beneficial. The plant recommended for this demonstration is the Back River WWT facility in Baltimore, Maryland.

The Back River plant is owned and operated by the city of Baltimore. It is a secondary treatment facility occupying a 466 acre (1.9×10^6 m^2) wooded site in the eastern part of Baltimore County at the head of Back River. The collection system discharging to the Back River plant serves an area of 140 mi^2 (362×10^6 m^2) with an estimated population of 1.3 million. The plant treats approximately 90% of the wastewater generated from Baltimore City and Baltimore County.

Several possible siting options for the fuel cell have been identified at the facility's new egg-shaped digesters. Two of the sites are near the thermal generation building, which would facilitate heat recovery. Back River strongly favors heat recovery for economic reasons, and these are the preferred sites for the demonstration. While the H_2S content of the ADG produced by the Baltimore plant is lower than the other facilities surveyed, Table 4, the basic principles of the gas cleanup system will be verified by testing at the facility. The exit sulfur concentration from the gas cleanup system is critical in determining fuel cell life. Inlet concentration determines the required intervals between bed replacements and consequently operating/maintenance costs. Economic analyses were based on high inlet concentrations of sulfur to the gas cleanup system.

Advanced Technology Studies

IFC has ongoing activities to improve the operating characteristics and lower the cost of their natural gas fueled PAFC. Under this program, a number of advanced technology options were investigated to determine their potential benefit to a commercial fuel cell for the ADG application.

The technology improvements considered were related to the fuel processor, the fuel ejector, water recovery, controls, and heat recovery.

The results of these investigations identified several areas of technology improvements beneficial to fuel cells in ADG applications that are considered worthy of further activities. These are listed in Table 5.

Table 4. *Typical Digester Gas Compositions (Dry Basis)*

	Baltimore	Nassau County		NYC DEP	Philadelphia Water Dept.	Orange County Calif.
	Back River	Bay Park	Cedar Creek	26th Ward		
Heating Value HHV, Btu/SCF	N/M	670	N/M	636	N/M	N/M
Methane, vol %	60.9	66.0	57.2	62.0	62.0	65.6
Carbon Dioxide, vol %	37.8	32.6	38.9	36.1	34.0	33.4
Nitrogen, vol %	1.0	0.92	3.82	0.97	N/M	1.0
Oxygen, vol %	0.3 (est.)	0.45	N/M	0.20	N/M	0.03
Hydrogen Sulfide, ppmv	6.0	80	170**	100	<500**	81
Halides, ppmv	<1.0	ND*	N/M	<1	N/M	<4
NMOCs, vol %	<0.0005	ND*	0.01**	ND*	N/M	<0.001

N/M—Not measured
** Not detected (level of detection not specified)*
*** Value set from equipment specifications, not from analyses*

Conclusions

This study has confirmed that fuel cell power plants have many benefits to the operator of a WWT plant. The issues associated with the use of a gas produced by such a plant in a fuel cell power plant designed for natural gas have been identified and straightforward technical solutions to these issues have been defined. One of these issues is associated with removal of the H_2S contained in the ADG. A test of a cleanup system to remove this impurity has been designed, and it is recommended that this system be tested. A site for this cleanup system test and the subsequent demonstration fuel cell has been selected. This site, in Baltimore, Maryland, at the Back River WWT facility, provides the opportunity for demonstrating high operating efficiency and low emissions on ADG.

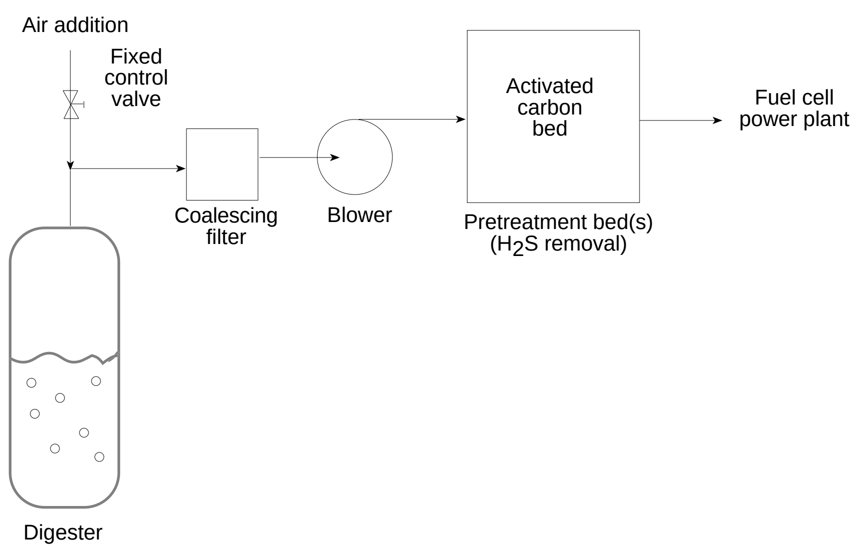

Figure 2. *Gas cleanup unit schematic.*

Table 5. Technology Areas Recommended for Further Assessment

Technology Area	Potential Power Plant Benefit: Reduced Cost	Increased Efficiency	Low Emis-sions	Increased Quan/ Qual Heat	Waste Water Treatment Plant Impact/Issue	Results	Further Activities Warranted
Fuel Processor	✓	✓	✓		Operation of reformer on dilute burner gas.	• Low emissions maintained by increasing flame temp.	Yes
Ejector/Fuel Control		✓			Operation of ejector on dilute fuel gas.	• Advanced ejector shows no benefits compared to existing ejector.	No
Water Recovery	✓				Shell and tube condenser presently used. Look to replace with lower cost contact cooler.	• Cost savings offset by effi-ciency loss	No
Controls	✓		✓		Advanced controls could reduce power plant cost. Use of O_2 sensors in exhaust could provide more efficient reformer operation on ADG.	• Several areas look promising and warrant further effort and monitoring.	Yes
Heat Recovery				✓	Maximizing waste heat quantity/quality could provide for better integration with waste water plant	• System changes, identified to increase thermal quality/quantity, do not require technology development.	No

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The complete report, entitled "Demonstration of Fuel Cells to Recover Energy from an Anaerobic Digester Gas—Phase I. Conceptual Design, Preliminary Cost, and Evaluation Study," (Order No. PB95-187381, Cost: $19.50, subject to change) will be available only from

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