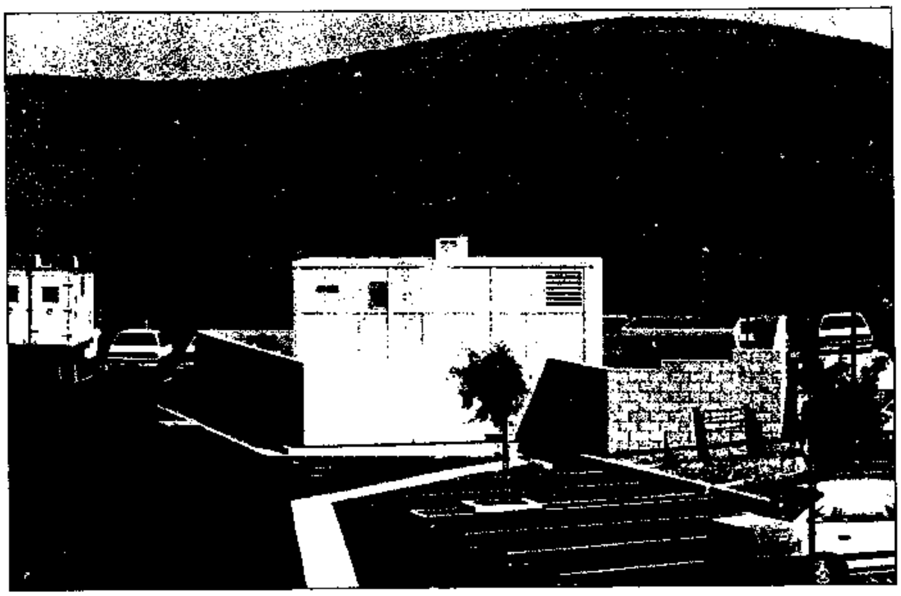
Using Landfill Gas in Fuel Cells—A Step Closer to Commercial Reality

A recent demonstration project may encourage more use of landfill gas in fuel cells, the cleanest energy conversion technology available today.

By John C. Trocciola, John L. Preston, and Ronald J. Spiegel

Early 1995 marked the completion of the first steps toward a promising new beneficial use for landfill gas. The first demonstration using methane from landfill gas in a phosphoric acid fuel cell was successful, signalling that a new way to produce electricity and reduce air emissions is closer to commercial reality.



Looks like any other industrial white box, but inside is a 200-kilowatt fuel cell power plant that was the first to generate power from landfill gas. The cell is now being installed for use in a second demonstration of the technology in Connecticut. (photo courtesy International Fuel Cells, Windsor, CT)

During the past 20 years, many landfills have designed systems to mitigate landfill gas emissions that contribute to global warming. Gas collection systems are in use in more than 150 landfills today. The conventional control approach has been to burn the collected gas in flare systems, but a growing number have begun to use the gas in beneficial energy projects. Burning gas in internal combustion engines (ICEs) to drive an electrical generator has become the most common means of using landfill gas. Of the approximately 180 landfill gas-to-energy projects operating in North America, roughly two-thirds use ICEs to generate electricity. However, because of the expense to develop projects and concerns about emissions from ICEs, the search continues for technologies that can reduce air emissions, lower capital cost, and still make beneficial energy use of the methane.

Fuel cells have emerged as one technology that may improve the outlook for efficient energy use of landfill gas.

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Program Description

In 1990, the U.S. Environmental Protection Agency awarded International Fuel Cells Corporation (IFC) a contract to demonstrate landfill gas control with energy recovery using a commercial phosphoric acid fuel cell. Early in 1995, IFC completed a three-phase program showing that the concept is environmentally feasible in commercial operation. The program addressed two principal issues: (1) a gas cleanup method that would remove contaminants from the gas sufficiently for fuel cell operations, and (2) successful operation of a commercial fuel cell power plant operating on methane-rich gas from landfills.

Phase I, consisting primarily of a conceptual design, cost, and evaluation study, was initiated in January 1991.[1] Phase II addressed contaminant removal from landfill gas, including the construction and testing of a module designed to remove contaminants from the gas. Phase III tested a PC25™ fuel cell at an existing landfill gas-to-energy facility at the Penrose Landfill in Sun Valley, California, which is owned by Pacific Energy Corporation. This article describes Phase II and Phase III work.

Landfill Gas Cleanup

Landfill gases consist primarily of carbon dioxide (CO_2), methane (CH_4), and nitrogen (N_2), plus trace amounts of hydrogen sulfide (H_2S), organic sulfur, organic halides, and non-methane hydrocarbons. Nitrogen is not a true constituent of landfill gas, but is drawn into the mix when vacuuming gas into the collection system. The concentration varies widely, with highest concentrations occurring from the landfill's perimeter wells. The specific contaminants in the landfill gas of concern to the fuel cell are sulfur and halides. Both of these components can "poison" and, therefore, reduce the life of the power plant's fuel processor. The fuel processor is the unit which converts methane in the landfill gas into hydrogen (H_2) and CO_2 in an endothermic reaction over a catalyst bed. The catalyst in this bed can react with the halides and sulfides and lose its activity. This reaction, when it occurs, is irreversible.

The Gas Pretreatment Unit (GPU) designed to remove fuel cell contaminants is shown in Figure 1. H_2S is first removed by adsorption on a packed bed. The material which performs this func-

Background on Fuel Cells

A fuel cell operates much like a battery, but consumes an external gaseous (hydrogen- and oxygen-rich) fuel instead of internal electrodes, to produce electricity. With negligible emissions, fuel cell power plants are the cleanest fossil fueled electric generating systems. A fuel cell power plant converts up to 55 percent of the fuel energy in natural gas into electricity, compared to about 35 percent in a conventional power plants.

A fuel cell power plant has three major sections: a fuel processing or reforming section, the fuel cells, and a power conditioning section. The fuel processing section must convert the fuel into hydrogen and also clean the fuel of impurities that might poison the operation of the cell. The power conditioning section converts direct current into alternating current suitable for distribution. Because each cell has a relatively low output, cells are stacked to achieve desired power outputs.

Three types of fuel cells with the most promise for commercial use are distinguished by their electrolytes—phosphoric acid, molten carbonate, or solid oxide. Phosphoric acid cells are the furthest along in commercial development. There are 61 units operating around the world.

The Penrose Landfill demonstration was the first fuel cell project to use landfill gas instead of natural gas. At the conclusion of the demonstration, the fuel cell was dismantled for relocation to a landfill in Connecticut for a one-year demonstration. A project to demonstrate use of landfill gas in a molten carbonate cell will begin construction late in 1995 in Anoka County, Minnesota.

tion is a specially treated carbon, activated to catalyze the conversion of H^2S into elemental sulfur which is deposited on the bed. The reactions for the conversion of sulfur, the Claus Reactions, are:

$$H_2S + 1/2\ O_2 \rightarrow H_2O + SO_2$$

$$SO_2 + H_2S \rightarrow H_2O\ + S$$

The bed is not regenerable on site, but must be removed to another site if regeneration is desired.

The first stage cooler removes water, some heavy hydrocarbons, and sulfides which are discharged as condensate to the Penrose plant's existing water condensate pretreatment system. Since the demonstration landfill GPU operates on a small slipstream from the Penrose facility's compressor and gas cooler, some of the water and heavy hydrocarbon species are removed before the GPU. Most of the contaminant halogen and sulfur species are lighter and remain in the landfill gas to be treated in the pretreatment unit. Remaining water in the landfill gas, as well as some sulfur and halogen compounds, are removed in a regenerable dryer bed which has a high capacity for adsorbing the remaining water vapor in the landfill gas. There are two dryer beds so that one remains operational while the other is being regenerated.

Table 1: Landfill Gas Contaminant Removal Performance of the GPU (in ppm)

	GPU Inlet	Specified Value	GPU Exit
Total Sulfur (as H_2S)	117	<3	≤0.047
Total Halides (as chloride)**	47	<3	≤0.032

* Measured by gas chromatography/flame photometric delineation by EPA Methods 15,16 and 18
** Measured by gas chromatography/mass spectrometry by EPA Method TO-14

The dry landfill gas is then fed to the second stage cooler. This cooler can be operated as low as -32°C and potentially can condense additional hydrocarbons if present at sufficient concentrations. The second stage cooler also reduces the temperature of the carbon bed, thereby enhancing its adsorption performance.[2]

The downstream hydrocarbon adsorption unit, which has its temperature controlled by the second stage cooler, is conservatively sized to remove heavy hydrocarbon, sulfur, and halogen contaminant species in the landfill gas. This unit consists of two beds of activated carbon so that one remains operational while the other is being regenerated. Both the regenerable dryer and hydrocarbon removal beds operate on a nominal 16-hour cycle, with each set of beds operating in the adsorption mode for 8 hours and in the regeneration mode for 8 hours.

The gas then passes through a particulate filter and is warmed indirectly by an ambient air, finned-tube heat exchanger to attain a fuel inlet above 0°C before being fed to the fuel cell unit.

IFC completed construction of the GPU in February 1993. It was evaluated at IFC's facility in South Windsor, Connecticut, using N_2 as the test gas. A 16-hour control test verified that rated flows, pressure, and temperature were being achieved. The GPU was installed at the Penrose Landfill in April 1993, and it had operated for more than 2,000 hours by early 1995. The GPU removed the sulfur and halogen compounds contained in the landfill gas to a level significantly below the specified value of less than 3 parts per million/volume (ppmv). See Table 1.

The low level of contaminants exiting the GPU indicates that the low temperature cooler is not essential, even though the reduced temperature in the activated carbon bed increases capacity for sulfur and halogen compounds. For future installations, it may be beneficial to eliminate the low temperature cooler and simplify the refrigeration system in exchange for increasing the activated carbon bed value slightly. Based on the favorable results of the GPU testing, the EPA directed IFC to proceed into Phase III, which entailed characterizing the performance of the commercial phosphoric acid fuel cell power plant—in terms of emissions, efficiency and power output—when operating on landfill gas purified by the GPU.

Fuel Cell Testing

The power plant used in the demonstration is a commercial ONSI PC25 200-kilowatt phosphoric acid fuel cell. The power plant, designed to run on pipeline natural gas but modified to run on purified landfill gas, was shipped and installed at the Penrose Landfill during 1994. The unit was operated on natural gas before its modification, in order to establish a baseline performance level. After modification for low Btu gas, it was connected to the GPU for testing on landfill gas.

Power produced by the unit was fed into the electrical grid for sale to the local electrical utility, the Los Angeles Department of Water and Power (LADWP). It was the first fuel cell ever connected to the LADWP grid. The revenue produced by the sale of electricity was used to help offset program costs.

Table 2 presents results of emission testing of the PC25 power plant at the Penrose Landfill conducted during February 1995. The emission levels indicate that fuel cells can operate on landfill gas while maintaining the low emission levels characteristic of this type of fuel cell. Additional performance data will be contained in the final report on Phase III.

Unlike internal combustion engines and turbines used to generate electricity from landfill gas, the PC25 (and other fuel cells) offer advantageous siting characteristics, among them low levels of emissions, noise, and vibration. In addition to the electric power it generates (200 kw), the PC25 can produce 760,000 Btu per hour of thermal energy. By siting the power plant away from the landfill, its thermal energy can be put to constructive use at a customer's building. Siting at a customer's

Table 2: Emission Test Results from Fuel Cell Operating on Landfill Gas

Pollutant	Fuel Cell Emission
Sulfur Dioxide (SO_2)	Non-detect*
Nitrogen oxides (NO_x)	0.12 ppm, avg.
Carbon Monoxide (CO)	0.77 ppm, avg.

* Detection limit for SO_2 was 0.23 ppm; all data are dry measurements corrected to 15% O_2.
Tests used EPA Methods 6c, 7e and 10

building also improves the economics significantly, in two ways: 1) the power plant owner can sell power at higher rates than it would get from a utility, and 2) the power plant owner can sell heat to the customer. The power plant displaces the higher-cost commercial electricity the customer is buying. The fuel cell project owner can sell power to the customer at a rate somewhere between the customer's former rate and the "avoided cost" rate the power plant would receive if it sold the power to the utility.

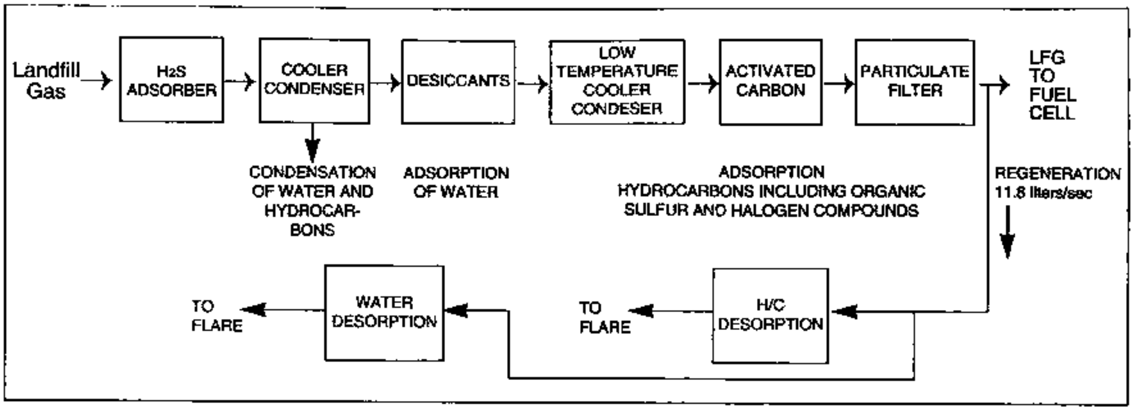

Figure 1: Landfill Gas Pretreatment System

Utilizing the fuel cell's thermal energy can result in an overall efficiency of 80 percent. (Efficiency as used here is the electrical energy plus thermal energy divided by the energy content of the gas consumed.) This high efficiency conserves natural resources and reduces CO_2 emissions.

Conclusion

Methane emissions from landfills and other sites are potential contributors to global warming. Conventional methods to mitigate these emissions, such as flaring, produce other greenhouse gases, such as CO_2. Operating a fuel cell at a landfill site can eliminate methane and other universal secondary emissions (CO, SO_2, NOx), lowers total CO_2 emissions, and can permit efficient generation of electric power. In order to operate a fuel cell on landfill gas, the gas must be sufficiently purified. A landfill gas cleanup pretreatment module designed, constructed, and tested in this demonstration was successful. The combined gas cleanup system and power plant produced electrical power with low levels of air pollution.

Notes:

[1]Sandelli, G.J., "Demonstration of Fuel Cells to Recover Energy from Landfill Gas," Phase I Final Report: Conceptual Study.

[2]Graham, J.R., and Ramaratnan, M., "Recovery of VOCs Using Activated Carbon," Chemical Engineering, Vol. 100, No. 2, February 1993.