Coming Clean with Fuel Cells

An Innovative Emission-Offset Project That Utilizes Anaerobic Digester Gas-Powered Fuel Cells to Produce Electricity

FUEL CELLS, UNTIL RECENTLY A CURIOSITY LARGELY CONFINED TO THE SPACE program, are emerging as a valuable clean and efficient generator of electricity. A number of companies are developing fuel cells for use in stationary applications. Most of the current applications for fuel cells utilize natural gas as a fuel. In certain states, such as New York and Connecticut, fuel cells operating on natural gas are recognized by the state as a renewable energy source. Recently, however, fuel cells, mostly phosphoric acid, have been shown to operate well on renewable biogas fuels, such as anaerobic digester gas (ADG) produced at wastewater treatment plants as well as landfill gas (LFG) and gas produced at beer breweries.

While the present cost of a stationary fuel cell is high, there are certain "niche" applications for which that higher price is justified. These niche applications offer utilities opportunities to provide additional value and better serve their customers, and they provide new business opportunities. Three very good examples of such high-value applications by the New York Power Authority (NYPA), working together with its customers, include:

- ✔ use of eight fuel cells at four New York City Department of Environmental Protection (NYC DEP) wastewater treatment facilities (WWTFs) to offset emissions from conventional small power plants (combustion turbines previously installed by NYPA in New York City)
- ✔ use of a fuel cell at Westchester County's Yonkers Joint Wastewater Treatment Plant to avoid flaring emissions
- ✔ use of a fuel cell at the New York City Central Park Police Precinct Building (Figure 1) to upgrade the building's electrical system and defer costly infrastructure improvements in an environmentally friendly way. This fuel cell supplied electricity to the precinct throughout the August 2003 blackout.

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WWTFs represent a growing niche for distributed generation. Many WWTFs in the United States and abroad utilize a process called anaerobic decomposition to purify water prior to discharging it into a river or bay. According to U.S. Environmental Protection Agency statistics, there are over 16,000 WWTFs in the United States, of which about 3,400 (21%) use anaerobic decomposition as part of their process. Less than 2% (about 260 facilities) use digester gas for energy production. While the process of anaerobic decomposition is very effective in reducing water pollution, many WWTFs flare off the gas produced during the digester process, which increases air pollution and contributes to the greenhouse warming effect.

NYPA, the nation's largest state-owned electric utility, pioneered an innovative emission offset project by installing fuel cells powered by ADG at WWTFs in New York City to achieve zero-emissions impact from conventional gas turbine power plants. As can be seen from Table 1, NYPA currently owns 2.4 MW of fuel cell capacity and operates 12 fuel cells at eight sites. Nine of the 12 fuel cells are powered by ADG. Most of these units supply both electricity and heat to the host facility with virtually no emissions.

In the early 1990s, NYPA recognized the potential beneficial impact of utilizing ADG produced at WWTFs as an untapped "free" renewable fuel resource for distributed generation. NYPA has since been a national leader in advancing this technology and installed the world's first commercial fuel cell (manufactured by UTC Fuel Cells) powered by ADG at Westchester County's Yonkers WWTF. This project is currently supplying electricity and heat to the host facility while dramatically reducing air emissions.

Wastewater Treatment Facilities

Anaerobic decomposition involves microorganisms that derive energy from metabolizing organic materials to decompose organic waste at WWTFs. In the absence of oxygen, the byproducts of their metabolism are carbon dioxide (CO_2) and methane (CH_4) plus trace quantities of other compounds, such as hydrogen sulfide (H_2S) and organic halides (mostly chlorides). ADG is primarily a mixture of these gases (60% methane and 40% carbon dioxide). A simplified diagram of the wastewater treatment process is shown in Figure 2.

ADG is generally collected and either used as fuel in boilers to keep anaerobic digesters warm, flared off, or, in some cases, used in internal combustion engines to produce electricity. At many WWTFs, ADG is being utilized inefficiently, or not at all. For example, many facilities are located in temperate climates in which the requirement for heat in the summer is minimal.

If ADG is released uncombusted, it significantly contributes to the greenhouse effect. This occurs principally through emissions of methane, which traps at least ten times as much heat as carbon dioxide. For this reason and for odor control, excess ADG is typically flared (burned) in flame towers, a process that eliminates methane emissions. However, flaring is only a partial solution, since ADG combustion generates photoreactive ozone precursors, such as nitrogen oxides and volatile organic compounds. As a result, all large WWTFs in the United States are regulated as stationary sources of air pollution under the federal Clean Air Act. All 14 WWTFs in New York City are designated and regulated as major pollution sources. This designation necessitates installation of control and monitoring technologies, which can be very costly. Fuel cells provide the most effective solution to these problems. They efficiently generate premium quality electricity and much needed thermal energy, while consuming ADG and emitting negligible amounts of regulated pollutants. In addition, they permit significant reductions in carbon dioxide emissions compared to flaring. As a result, WWTFs are primary candidates for clean distributed generation and for win-win partnerships between the WWTF operators and utilities.

Yonkers Fuel Cell: A Pioneering Project

In 1996, NYPA joined forces with International Fuel Cells (now UTC Fuel Cells), EPRI, the New York State Energy Research and Development Authority (NYSERDA), U.S. Department of Energy (DOE), and Westchester County at the Yonkers Joint Wastewater Treatment Plant to develop and demonstrate the first fuel cell in the Western Hemisphere powered directly by ADG.

Previous work performed by UTC and its partner, Toshiba, at the WWTF in Yokohama City, Japan, tested the concept of utilizing ADG in fuel cells. However, in this first field test, rated power could not be achieved without increasing the methane concentration in ADG to at least 90% using a pressure swing adsorption to remove carbon dioxide from the ADG.

For the Yonkers project, a 200-kW PC25C phosphoric acid fuel cell was modified to operate on ADG. This involved modifications to the cell stack assembly, reformer, thermal management system, piping, valves, controls, etc. ADG differs from pipeline natural gas in the following ways:

figure 1. The Central park fuel cell. It provided power during the August 2003 blackout.

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- ✔ ADG contains trace quantities of sulfur compounds, typically in the form of hydrogen sulfide and organic compounds, which contain chlorine. Both of these species can react with the catalysts in the reformer system, resulting in deactivation of the catalysts.
- ✔ ADG typically contains 60% methane, while natural gas contains methane in excess of 95%. This lower methane content of ADG results in a higher volumetric flow of gas, which can increase system pressure drops.

These differences required modification of the PC25C, originally designed to operate on natural gas only. These modifications were principally:

- ✔ Mechanical components, such as piping and valves, in the reactive gas supply system were modified/enlarged to accommodate the larger volume flow rates resulting from the use of diluted methane fuel. This modification helped reduce system pressure drops.
- ✔ An external gas compressor skid was added to raise the inlet pressure of the ADG to compensate in part for the increased pressure drops of the diluted fuel.

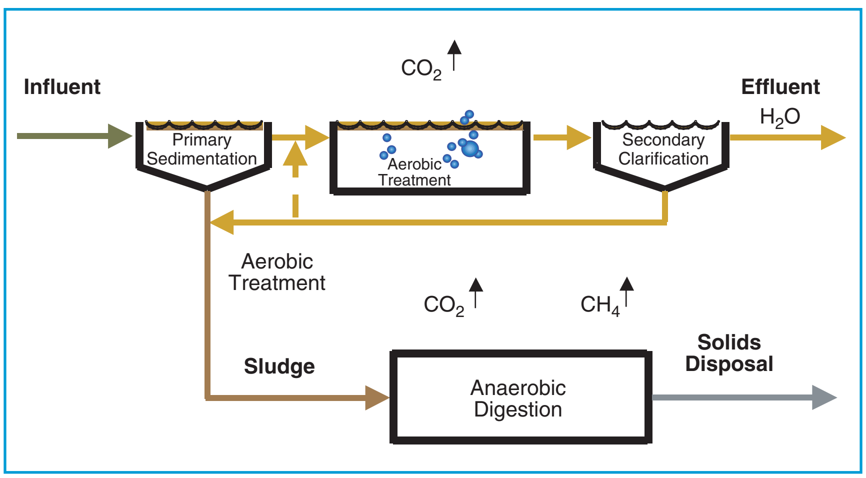

figure 2. The wastewater treatment process schematics.

- ✔ An external gas processing unit (GPU) was added to remove the hydrogen sulfide contained in the ADG stream. This GPU consists of a specially treated charcoal, which converts the hydrogen sulfide into elemental sulfur and water. The sulfur is adsorbed on the charcoal, which is then removed on a periodic basis; the water evaporates into the ADG stream; and the purified gas is fed to the fuel cell.
- ✔ A halide absorber was added internally to the PC25C to remove these compounds (mostly chlorides).
- ✔ Fuel-to-air ratios over the entire operating range were adjusted within the wider-than-usual boundaries to compensate for broader-than-anticipated methane concentration variations in ADG.
- ✔ Additional drains were installed in the facility fuel line to remove large amounts of entrained water periodically blocking ADG supply to the GPU.
- ✔ A blower was installed to compensate for lower-than-anticipated ADG pressure from the Yonkers WWTF.

The Yonkers WWTF processes 95 million gallons of raw sewage per day and generates 17,400 standard cubic feet (scf) of ADG per hour. About 70% of the ADG is used internally in boilers and engines and the rest is flared. The fuel cell captures 3,000 scf of this ADG that would otherwise be flared and uses it for power generation and hot water production. All electric and thermal energy produced by the fuel cell is consumed onsite. The fuel cell provides a valuable customer service by helping Westchester County to reduce air pollution from flaring, efficiently utilize onsite resources, and comply with Clean Air Act and other regulatory requirements.

New York City Fuel Cells: Offsetting Emissions

By the summer of 2000, it had become apparent that New York City could face serious power supply shortages as soon as the following summer. At the request of state officials, NYPA in late August 2000 began the process of procuring, siting, engineering, permitting, and installing ten General Electric LM 6000 simple-cycle gas-turbine units in the city. This process, which normally would take two years or more, was essentially completed within ten months. (NYPA installed an additional unit on Long Island, which also faced a potential capacity shortfall.)

As the small power plants were being installed at six sites in New York City, the New York Independent System Operator (ISO), which operates the state's power system and administers its wholesale electricity markets, forecast a capacity deficit of 397 MW in the city in the summer of 2001, absent the NYPA generators.

All of the new natural-gas-fueled plants in the city were in operation by mid-summer of 2001, generating a total of about 400 MW and effectively erasing the deficit forecast by the ISO. Their importance was vividly demonstrated in August of that year when a heat wave led to record demand for electricity in New York City and statewide. They have continued to play a vital role in meeting the city's power needs and were essential in restoring power to the New York metropolitan area after the August 2003 blackout.

NYPA made an extra effort to ensure that these LM 6000 turbines would be among the cleanest in the world. All turbines were equipped with catalytic reduction systems, keeping emissions of regulated pollutants substantially below the most stringent New York State permitting limits. As a result, the combined regulated emissions from these units were calculated at approximately 168 tons/year. Additionally, NYPA

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table 1. Fuel cells owned by the NYPA.

Location	Number of Units	Output (kW)	Fuel	Normal Operation
Yonkers WWTP	1	200	ADG	Grid-parallel
NYPD Central Park	1	200	Natural Gas	Grid-independent
N. Central Bronx Hospital	1	200	Natural Gas	Grid-parallel/ grid independent
NYC Aquarium	1	200	Natural Gas	Grid-parallel
26th Ward WWTP	2	400	ADG	Grid-parallel
Red Hook WWTP	2	400	ADG	Grid-parallel
Hunts Point WWTP	3	600	ADG	Grid-parallel
Oakwood Beach WWTP	1	200	ADG	Grid-parallel

pledged that it would offset any emissions, however small, from these generators to achieve "zero net emissions" for the gas-turbine program.

It was calculated that eight fuel cells operating at New York City DEP WWTFs would assure that NYPA met its "zero net emissions" goals. The total regulated emission reductions from eight fuel cells were calculated at 173 tons/year, with each fuel cell offsetting 21.625 tons/year of regulated emissions at 90% availability. Additionally, each fuel cell offsets 1,200 tons/year of CO_2 (a total of 9,600 tons annually for the eight units) and 0.3 tons/year of nonorganic hydrocarbons.

NYPA joined with NYC DEP, NYSERDA, the U.S. DOE, and the U.S. Department of Defense (DOD) to install the eight fuel cells. Con Edison's engineering staff worked closely with NYPA to help interconnect the fuel cells to that utility's grid. All eight fuel cells became operational by the fall of 2003. These fuel cells represent the next-generation ADG technology. They incorporate lessons learned from the Yonkers fuel cell operation in many areas, including:

- ✔ dual fuel (ADG and pipeline gas) capability to improve availability
- ✔ smaller reformer with lower pressure drop
- ✔ lower pressure drop across condenser, reformer burner, and cell stack gas manifolds
- ✔ cells in stack; more acid in cells to accommodate higher evaporation rate due to higher gas flows from ADG
- ✔ more rugged manifolds to accommodate higher ADG pressures and flow rates
- ✔ plume suppression systems for the three outdoor installations to eliminate water vapor
- ✔ ventilation systems for the indoor installation (Red Hook) to evacuate fuel cell purge products.

These eight fuel cells will allow DEP to substantially reduce emissions associated with ADG flaring, while generating electric power and thermal energy onsite for the benefit of its WWTFs. Photos of two installations are shown in Figures 3 and 4.

NYPA owns, operates, and maintains the fuel cells. By combining NYSERDA and U.S. DOD grants with its own financing, NYPA is able to sell the fuel cell electricity to DEP at a competitive price. The fuel cell power plants contribute an additional clean 1.6 MW to NYPA's in-city generation, making them dispatchable green-power resources. The fuel cells also assist NYPA in providing dependable and environmentally beneficial generation to serve its southeastern New York customers.

figure 3. The 26th Ward fuel cell installation with two 200-kW fuel cells and auxiliary equipment during construction.

figure 4. Oakwood Beach fuel cell installation with one 200-kW fuel cell and auxiliary equipment.

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Fuel Cells at Wastewater Treatment Plants

Wastewater treatment plants that utilize the anaerobic digestion process produce a gas mixture of about 60% methane (CH_4) and 40% carbon dioxide (CO_2), plus ppm levels of hydrogen sulfide and, in some cases, organic halides (mostly chlorides). This gas mixture, called ADG, may be utilized in a fuel cell to produce power and heat. However, the sulfur and halide compounds must be removed to prevent deactivation of certain key components in the fuel cell. An ADG fuel cell system is shown in the figure.

The ADG-powered fuel cells are constructed in three modules: a gas processing unit (GPU), a power module, and a cooling module. The GPU module is the unique new component specifically developed for this application.

The GPU accepts ADG directly from the anaerobic digesters and delivers a pretreated gas to the modified power module. The GPU, developed by UTC Fuel Cells in cooperation with the United States Environmental Protection Agency, consists of a demister to remove any entrained water and two beds of specially treated charcoal, which convert the hydrogen sulfide (H_2S) into elemental sulfur and water by reacting with air, which is fed separately to the unit. The unit utilizes nonregenerable potassium hydroxide-impregnated redundant activated carbon beds to remove hydrogen sulfides from ADG. The unit is sized to process ADG flows of up to 4,800 scf/hr. The two carbon beds are capable of operating for about six months with ADG containing 200 ppm of H_2S. Each bed contains approximately 1,200 lbs. of carbon. The GPU contains sampling ports so that the H_2S content may be monitored to determine when the beds need to be changed. The sulfur is adsorbed on the charcoal, which is then removed on a periodic basis; the water evaporates into the ADG stream; and the sulfur-free gas is fed to the fuel cell. The unit is designed such that the charcoal in one bed may be removed and replaced with fresh charcoal while the second bed is used to continue to purify the ADG. The chemical reaction that takes place in the bed is

$$H_2S(\text{gas}) + O_2(\text{gas}) = H_2O(\text{gas}) + S\ (\text{solid sulfur}).$$

After the ADG exits the GPU, it consists of methane, carbon dioxide, and very low levels of organic halides and water. The methane can be used as a fuel in the power plant; the carbon dioxide merely acts as an inert gas in the system and, therefore, need not be removed. However, the halide compounds can deactivate fuel cell components. Therefore, they are removed inside the fuel cell prior to reaching those components that they can affect. To achieve this removal, a halide adsorption bed is added to the fuel processing stream inside the fuel cell power plant, where it is incorporated into the reactant supply system. Prior to entering this bed, the organic halide compounds are converted, inside the power plant, into inorganic halide compounds. These compounds are adsorbed onto the halide bed.

A standard PC25C power module reactant supply system is sized for natural gas with a nominal heating value of 980 to 1,200 BTU/scf (HHV). The modifications required to operate on ADG with nominal heating values

ADG Potential in New York

A positive environmental impact from a broad fuel cell market penetration and elimination of ADG flaring will result in substantial reductions in emissions of major regulated air pollutants. Additionally, 30% CO_2 reduction (compared to conventional generation) will result from the fuel cell operations. There is also no particulate matter in fuel cell emissions. Moreover, each PC25C fuel cell saves approximately 3,000 barrels of oil per year.

Fuel cells are among the most efficient commercially available methods of converting carbon-based fuels into usable heat and electricity. The fuel cell emission levels are more than an order of magnitude below those from other technologies and federal and local standards. Additionally, the pretreatment system eliminates problems associated with the corrosive nature of ADG. As a result, PC25C fuel cells are already exempted from air permit requirements in the South Coast (Los Angeles, California) and Bay Area (San Francisco, California) Air Quality Management Districts, the most stringent air management districts in the United States and maybe in the world. The states of Massachusetts, Connecticut, and Rhode Island are also considering air permit exemptions. NYPA's permitting experience has convincingly demonstrated that fuel cells easily meet all New York State air quality requirements.

New York State has been a pioneer in using fuel cells. There are now 26 fuel cells operating in New York, 12 of which are owned and operated by NYPA. Over the next few years, there will be even more fuel cells installed. Fuel cells can become a decisive factor in resolving New York State's air problems and reducing its dependence on imported oil.

NYC DEP operates 14 WWTFs and NYPA supplies power to 13 of them. The excess ADG generated by these facilities, and currently flared, is sufficient to generate at least an additional 5 to 10 MW of electricity and, conservatively, power at least 25 to 50 more 200-kW fuel cells. Additional

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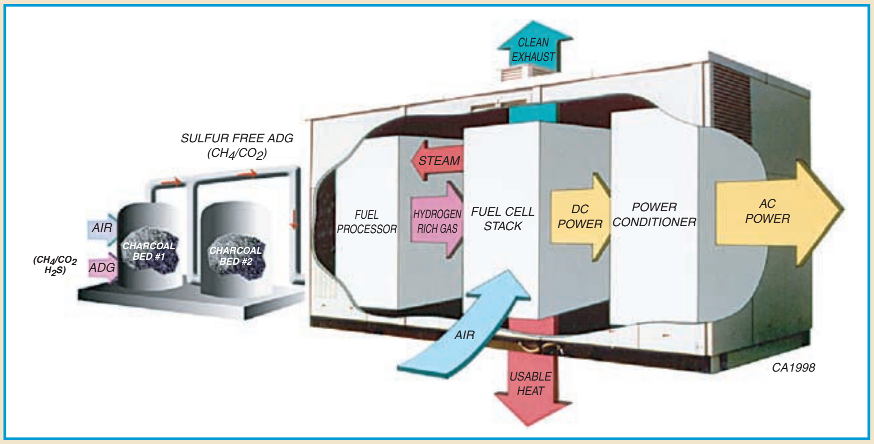
of 500 to 700 BTU/scf consist primarily of resizing inlet fuel valves and piping to reduce pressure drop and increase fuel flow capacity. Power module controller settings are tuned to maintain the appropriate level of process fuel, steam, and burner air when running on ADG. Additionally, ADG software modifications are implemented, and a separate natural-gas piping to the reformer start-up burner is provided. This separate piping will supply natural gas during start-up of the fuel cell.

The purified ADG from the GPU flows to the fuel processor, which consists of a metal vessel containing catalyst. In this vessel the methane in the ADG reacts with steam produced by the fuel cell stack to produce a stream consisting mostly of hydrogen and carbon dioxide; the CO_2 contained in the ADG does not react but passes through as an inert diluent. The hydrogen production reaction is

$$CH_4(\text{gas}) + 2H_2S(\text{gas}) = 4H_2(\text{gas}) + CO_2(\text{gas}).$$

The hydrogen is fed to the fuel cell stack where it reacts electrochemically with air to produce power, water vapor, and heat. A portion of the product water vapor is condensed into a liquid, vaporized by cooling the fuel cell stack, and then used in the fuel processor to react with the methane. Any hydrogen not utilized in the fuel cell stack (<5%) is combusted to provide the heat required by the fuel processor. The product water and carbon dioxide are exhausted to the ambient air. Any fuel cell heat not used to boil water for the fuel processor is available for use in the WWT process.



ADG fuel cell system schematics.

The GPU includes the gas analysis unit consisting of a sample pump, regulator, and H_2S detector cell. The H_2S sensor detects any hydrogen sulfide in the gas entering the fuel cell, and it provides a signal to the fuel cell controller to initiate an alarm or a safe shutdown before damage can occur.

The fuel cell stack dc is converted to 480 Vac using a static inverter.

major air quality improvements may be achieved if fuel cell applications are extended to utilize ADG currently burned in engines and boilers at WWTFs.

Biographies

Yan Kishinevsky has been with the New York Power Authority since 1980. He is the manager of distributed generation and energy utilization programs in the New York Power Authority's Research and Technology Development Division, responsible for the development and deployment of distributed generation technologies for the Authority customers. Prior to that, he held various positions with the Authority, including that of manager, special projects, in the Nuclear Generation Department and business development manager in the New Business Division. Prior to joining the Power Authority, Kishinevsky worked for Ebasco Services in New York City and in the Russian power industry. He obtained his B.S. and M.S. degrees in applied physics in the former USSR. He is a licensed professional engineer in New York State. He has authored over 40 technical papers and published numerous articles in the power industry magazines.

Shalom Zelingher is the director of research and technology development at the New York Power Authority (NYPA). He is responsible for formulating, developing, and implementing new technologies to benefit NYPA's core business and its customers in the areas of power system application, energy utilization, distributed generation, and renewable energy. He received his B.S.E.E. and M.S.E.E. from the Polytechnic Institute of New York. Prior to joining the Power Authority, Zelingher worked for American Electric Power Service Corporation. He is a senior member of the IEEE Power Engineering Society and the IEEE Industry Applications Society and CIGRE (International Conference on Large High Voltage Electric Systems). He is the co-author of over 40 technical papers.

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