

The Past, Present, and Future of Phosphoric Acid Fuel Cells Operating on Anaerobic Digester Gas

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ABSTRACT

With high efficiency, virtually zero emissions, and 24/7 generation capability, fuel cells represent the cleanest means of generating continuous on-site electrical power of any available technology. When fueled by the waste gases (anaerobic digester gas, ADG) from anaerobic digestion-based wastewater treatment facilities, stationary fuel cells can turn an emissions liability into a revenue-generating asset, while significantly reducing emissions of both air pollutants and greenhouse gases. ADG fuel cell applications often qualify for sizeable government incentive programs given the widespread acceptance of ADG as a renewable fuel. The PureCell™ fuel cell power system from UTC Power has accumulated more than 400,000 hours of operation on ADG at 22 installations worldwide. This article will describe the capabilities of the PureCell system operating on both natural gas and ADG, as well as the experience gained from UTC Power's fleet. Current and future product offerings will be presented with specific emphasis on opportunities for ADG applications.

PURECELL™ MODEL 200

The PureCell™ Model 200 is a stationary power generator based on phosphoric acid fuel cell technology.¹ Commercially available since 1991, more than 260 PureCell systems have been installed worldwide

¹ PureCell™ is a trademark of UTC Power.

and have accumulated over 1.25 billion kilowatt-hours of operating experience. UTC Power, a division of United Technologies, is actively marketing the current Model 200, and is investing significant research and development funding into advanced phosphoric acid fuel cell systems. UTC Power believes in the future of fuel cells as a long-term solution for improving energy security and reliability, as well as a means of achieving a sustainable energy supply. A PureCell system installed at a college in New Jersey in 2003 is shown in Figure 1.



Figure 1. PureCell™ Model 200 Installation, Stockton College, NJ

System Description

The PureCell™ Model 200 is a complete system for generating 200 kilowatts, 480-volt AC, electrical power that can be fueled by either natural gas or anaerobic digester gas (ADG). Figure 2 shows a schematic representation of the product in operation. The process starts with an internal fuel processor that converts the natural gas (or methane-rich ADG) into a hydrogen-rich gas used to power the fuel cell reaction in the fuel cell stack. An electrochemical reaction occurs in the fuel cell between the hydrogen and oxygen from air to generate electricity, heat, and water. Unlike conventional combustion technologies, there are no moving parts in the fuel cell, and the lack of combustion results in extremely low levels of unwanted chemical emissions such as nitrogen oxides and particulate matter.

At the end of the process is an inverter-based power conditioning system for converting the direct current (DC) power generated in

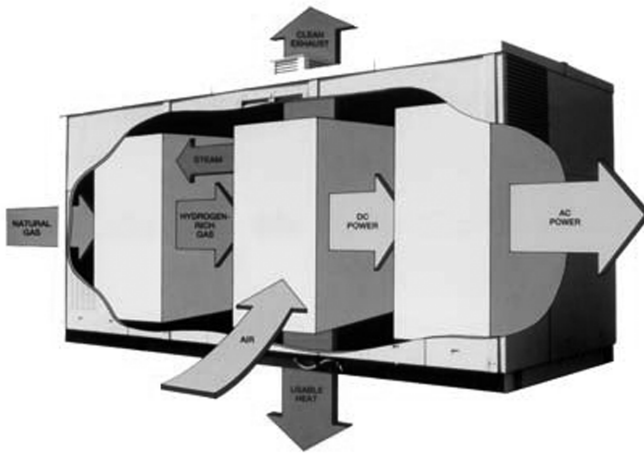


Figure 2. PureCell™ Model 200 in Operation

the fuel cell stack to alternating current (AC) power for supplying the electrical grid and customer loads. By virtue of the advanced power electronics, the power generated by the Model 200 is of a superior quality and capable of supporting sensitive electrical systems such as data-processing systems. The power plant is designed to operate connected to, and in parallel with, the electrical utility service for a facility, but can switch to grid-independent operation in the event of a grid outage. The standard switch-over time to grid independent operation is less than five seconds, but with a static switch, this time can be reduced to less than a 1/4 cycle, providing customers with seamless power through a grid failure.

For operation on anaerobic digester gas, a pre-processing gas cleanup system is required to remove contaminants that are typically present in ADG. Figure 3 shows the components of this assembly. A coalescing filter is first used to remove entrained moisture and solids that may be present in the gas. Treated, activated carbon beds are then utilized to remove hydrogen sulfide (H_2S), which, if unfiltered, would reduce the life and performance of the fuel cell system. The dual carbon beds are designed to be serviced independently without shutting down the power plant, and contain a volume of carbon sufficient for a six-month life at an average H_2S concentration of 200 ppm. A blower may be required to raise the pressure of the fuel into the power plant if the ADG pressure is insufficient.

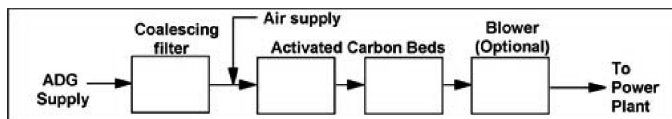


Figure 3. ADG Gas Cleanup System Schematic

Operation on low-Btu content gas such as ADG also requires some internal modifications in the Model 200 to handle the higher volume flow required to generate 200 kW. These modifications are factory-built and tested and mostly involve increasing the flow capacity of fuel control elements such as piping and control valves. Power module controller parameters are also tuned for optimum performance on the low-Btu fuel.

Performance

Performance characteristics for the PureCell Model 200 operating on both natural gas and anaerobic digester gas are shown in Table 1. Fuel cells have superior electrical efficiency versus traditional thermal cycles, such as engines and turbines, because the fuel cell reaction directly generates electricity from the chemical energy of the fuel. The initial efficiency of the Model 200 exceeds 41%, but slowly decreases over time to an average lifetime efficiency of 37% on natural gas. Performance on anaerobic digester gas will vary depending upon the methane content, or heating value, of the gas. 200 kW power output can be maintained for any methane concentration above 60%. Efficiency is slightly lower for ADG fuels because of the lower heating value and associated increase in fuel volumetric flows.

The Model 200 is provided with integral heat exchangers for the recovery of waste heat for such applications as domestic and process water heating and hydronic space heating. A maximum of 970,000 Btu/hr is available (lifetime average) for low-grade heat applications up to 140°F, or 435,000 Btu/hr for high-grade heat applications up to 250°F, with the balance still available as low-grade heat. Overall efficiencies up to 90% can be achieved for applications where all of the heat can be usefully applied.

Fuel Specification

Fuel specifications for operating on both natural gas and ADG are shown in Table 2. The standard Model 200 operates on low-pressure

Table 1. PureCell™ Model 200 Performance

<i>Characteristic</i>	<i>Units</i>	<i>Performance (Natural Gas)</i>	<i>Performance² (Anaerobic Digester Gas)</i>
Power output		200 kW	
Voltage, frequency (optional 400 VAC, 50 Hz)		480 VAC, 60 Hz	
Electrical efficiency ¹		37%	35%
Heat rate ¹	Btu/kWh	9,224	9,751
Fuel flow ¹	SCF/hr	2,050	3,500
Maximum heat available ¹ (@140°F)	Btu/hr	970,000	1,070,000
High grade heat available ¹ (@250°F)	Btu/hr	435,000	475,000
Maximum overall efficiency		90%	90%
Noise, dB(A) @ 30ft		60	60

Notes:

1. Specifications represent averages over operating life and are based on a lower heating value for natural gas of 925 Btu/scf.
2. ADG specifications based on methane content of 60%. Higher methane content will result in improved efficiency.

pipeline-quality natural gas and, unlike micro-turbines and other fuel cell systems, there is no requirement for a gas booster. Although the quality of most natural gas is sufficient for operation, high levels of nitrogen and oxygen can cause problems. Anaerobic digester gas must have at least 60% methane content for operation at 200 kW. Carbon dioxide, which is generally the second most abundant gas in ADG, has no detrimental effect on the fuel cell other than to increase the volume of gas that must be handled. Contaminants of particular concern for ADG applications are hydrogen sulfide, organic sulfur, and halide compounds. Because of the higher volume of low-BTU ADG gas required, a higher fuel pressure is required, and sometimes a low-pressure blower must be incorporated into the gas cleanup assembly.

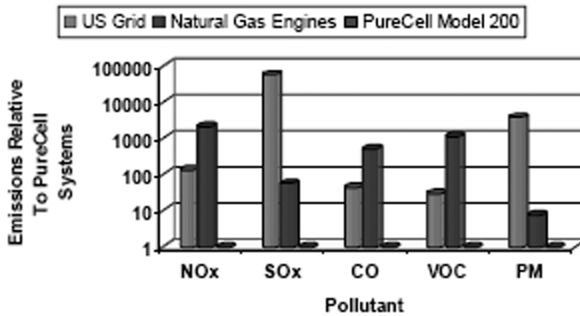
Table 2. Fuel Specifications

<i>Item</i>	<i>Units</i>	<i>Natural Gas</i>	<i>Anaerobic Digester Gas</i>
Methane (CH ₄)	% vol.	100 max	60 min.
Non-methane hydrocarbons	% vol.	10 max	N/A
Carbon dioxide (CO ₂)	% vol.	3 max	40 max
Water vapor (H ₂ O)	% vol.	N/A	5.5 max
Nitrogen (N ₂)	% vol.	4.0 peak/2.0 average	
Oxygen (O ₂)	% vol.	0.2 max	
Hydrogen sulfide (H ₂ S)	ppmV	N/A	1500 max/200 avg.
Total sulfur (S)	ppmV	30 max/6 avg.	N/A
Organic sulfur (S)	ppmV	N/A	1 max
Halides	ppmV	2 max	
Ammonia (NH ₃)	ppmV	0.5 max	
Olefins	% vol.	0.5 max	
Liquid water (H ₂ O)	lbs/hr	N/A	2 max/1 avg.
Pressure	in. w.g.	4-14	60 to 80 (3 to 20 w/blower)

Emissions: Air Pollutants

Fuel cells produce the lowest emissions of any available fuel-based power generation technology, with emissions levels of all common air pollutants significantly below competitive technologies. Figure 4 graphs pollutant emissions on a relative scale, demonstrating the orders of magnitude advantage of the PureCell system versus the U.S. utility grid averages and standard natural gas reciprocating engines. The PureCell system is certified to the strict emissions standards of the California Air Resources Board (CARB) for 2007 installation. Other distributed generation renewable technologies, notably solar and wind, surpass fuel cells as a clean energy source by producing essentially zero emissions for

every MW hour generated. This comparison can be deceiving; however, because of the low utilizations of these technologies. An installation of 1 MW of solar PV panels that demonstrates an overall utilization of 14% will require the owner to purchase the balance of the energy from the local utility. Thus, the PV panels only reduce emissions by 14%, whereas a 1 MW installation of fuel cells operating at 95% availability will reduce emissions by factors of 10 to 10,000, depending upon the pollutant. In short, although natural gas- (and ADG) powered fuel cells produce a small but measurable quantity of air emissions, the net positive impact of fuel cells on emissions reduction is more significant than equivalent installations of solar panels.



Note: US Grid emissions based on 2002 data from the US EPA, DOE/Energy Information Administration. Natural gas engines emissions based on US EPA AP-42 emissions factors (US EPA, AP-42, Fifth Edition, Compilation of Air Pollutant Emission Factors).

Figure 4. Relative Emissions of PureCell Systems Compared to the U.S. Grid and Natural Gas Engines

Emissions: Greenhouse Gases

Operating a PureCell system can result in a dramatic reduction of greenhouse gas emissions, especially when a high percentage of the waste heat is utilized to offset fossil fuel combustion. Up to 50% reduction in carbon dioxide emissions can be achieved when utilizing all of the waste heat, avoiding a total of 780 tons of CO₂ annually for a single PureCell Model 200. Emissions of other more powerful greenhouse gases such as NO_x, hydrocarbons (methane and non-methane), and water vapor are also significantly lower than standard combustion-based power generation.

APPLICATIONS AND FLEET HISTORY

UTC Power has supplied more than 260 PureCell systems to customers in 19 countries on 5 continents. The majority of applications have been combined heat and power solutions at commercial and industrial facilities. Building types include hotels, hospitals, data centers, schools, and office buildings. The systems are typically connected to the utility grid and generate continuous baseload electrical power. Most are designed to be isolated from the grid and continue to operate to serve critical loads even if the grid goes down, thereby providing both backup power and continuous energy savings. The heat from the fuel cell is used to support a variety of thermal loads including space heating, boiler preheat, domestic water and process water heating, and driving absorption chillers for providing chilled water and space cooling. Figure 5 shows a variety of applications. As is shown, PureCell systems can be installed indoors and multiple units can operate together to generate greater than 1 megawatt of power at one site.

UTC Power has the largest stationary fuel cell fleet in the world, with over 7 million operating hours and 1.25 billion kWhs of electricity generated. Table 3 summarizes this experience. The PureCell system features the most reliable and durable fuel cell technology on the market. The fleet average availability for 2005 was 95%, which includes all planned and unplanned power plant shutdowns. Forty-five fuel cell stacks have already surpassed the design life of 40,000 hours. The fleet leader, located at the Central Park Police Station in New York City, has been operating more than 60,000 hours, by far the world record operating life for any fuel cell stack.

Applications on Anaerobic Digester Gas

Twenty-two PureCell systems have been installed for operation on anaerobic digester gas: 15 in the United States, 6 in Japan, and 1 in Germany. Two in Japan were operated off the waste gas from brewery operations, while the balance worldwide has been installed at wastewater treatment facilities. The experience gained on ADG has been essential for modifying and fine-tuning the design to achieve high-power, reliable operation. Countless lessons learned have been incorporated into the design of the gas processing pre-treatment system as well as modification to the power module design for handling the low-Btu gas. One of the key lessons is to have a separate natural gas feed in addition to



*Data
Processing
Center*



*Multi-
Megawatt
Micro-Grid*



*Hospital
Cogeneration*

**Figure 5. Typical
On-site Power Ap-
plications**

Table 3. UTC Power Fuel Cell Fleet Statistics

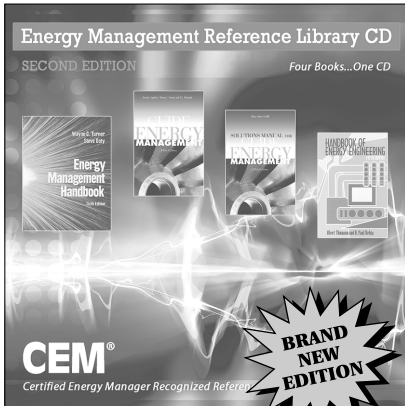
Number of systems installed	261
Operating capacity installed	52 MW
Operating hours	>7 million
Electricity generated	>1.25 billion kWh
Units (operating fuel)	
natural gas	238
anaerobic digester gas	22
hydrogen	1
Location	
US	144
Europe	28
Asia	85
Other	4
Fleet availability (2005)	95%

the primary ADG supply line. The natural gas is used for initial power plant start-up, as well as during times when the ADG supply is reduced or unavailable, which seems to be a frequent occurrence for anaerobic digester operations. The PureCell Model 200 control system is now able to automatically blend natural gas with ADG to maximize power output even as ADG supply is changing.

The leading customer for the PureCell ADG system has been the New York Power Authority (NYPA). NYPA owns and operates nine systems across five wastewater treatment facilities (WWTFs). The progressive utility pioneered fuel cells operating on ADG by installing the first commercial fuel cell system designed for ADG in 1996 at their Yonkers facility. After working through the early trials and developing confidence in the fuel cell technology, NYPA moved forward with a purchase of eight more systems. These eight systems were an emissions

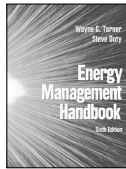
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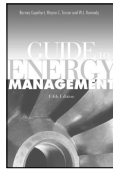


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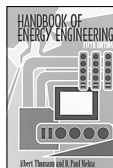


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offset solution for a NYPA plan to install new gas turbine power plants around New York City. By operating the eight fuel cell systems on the waste gas, which at the time was being flared, NYPA was able to offset the emissions from 400 MW of new capacity. NYPA's installation of three PureCell systems at the Hunt's Point WWTF is shown in Figure 6. Although initially motivated by this emissions offset benefit, NYPA now realizes the economic benefits of operating fuel cells at WWTFs—turning waste gas into revenue.



Figure 6. NYPA Wastewater Facility, Hunt's Point, NY

Anaerobic digester sites, especially wastewater treatment facilities, are good applications for fuel cells for several reasons. The most obvious reason is that the methane-rich ADG is available at no cost, eliminating the primary cost of operating the fuel cell. Even if the cost of owning and operating the anaerobic digester equipment is used to calculate a fuel cost, ADG would be a bargain relative to natural gas. WWTFs also have all the necessary traits for on-site combined heat and power generation: round-the-clock operation, large electrical loads, and a steady use for waste heat, which is required to keep the digester process at the optimal temperature for efficient biological decomposition. And the ultra-clean characteristics of fuel cell-generated energy match well with the core mission of WWTFs—reducing our impact on the environment.

THE FUTURE OF FUEL CELLS ON ADG

The potential markets for fuel cell systems operating on anaerobic digester gas are numerous and growing. According to the U.S. EPA, there are more than 16,000 WWTFs across the United States, with about 3400 utilizing the anaerobic digestion process for water treatment. Of these, only 2% (260) used the methane-rich off-gas for energy production in 2002. The ADG is more commonly burned, or flared, which not only wastes a valuable resource, but also adds air pollutants and greenhouse gases to our already over-burdened atmosphere.

Breweries and other beverage industries also hold promise for expanded applications because these companies are pressured to reduce their overall environmental impact. Another growing market is the use of anaerobic digestion on farms to reduce the impact of manure and other waste products, as well as to provide an additional source of revenue for the farming sector. The U.S. Department of Agriculture has a significant funding program available to help spur the use of anaerobic digestion on farms.

UTC Power is fully committed to the future of phosphoric acid fuel cell products and technology. The company has significant development plans to improve the PureCell system, which has already proven to be the most successful commercial fuel cell product in the world. The initial focus for engineering and development is to improve the fuel cell stack life to 10 years, which will significantly reduce the life-cycle cost of owning and operating the equipment. This new stack will first be integrated into the design of the current Model 200 to provide extended operational savings. An all-new power plant will then be developed with the target of a dramatic reduction in manufactured cost. Nominally targeted for an electrical output of 400 kW, the new model, currently in the conceptual design stage, will incorporate all the lessons learned from over 15 years of commercial experience. The increased power output, and an aggressive pursuit of design-for-manufacturing and service principles, will allow this new model to compete directly with conventional technologies without the need of federal or state financial incentives. Of course, all of the benefits of the PureCell system will be retained for the generation of clean, reliable, and cost-effective on-site and renewable power.

United Technologies Corporation, based in Hartford, Connecticut, provides high-technology products and services to the building and

aerospace industries. Its UTC Power unit, based in South Windsor, Conn., includes UTC Fuel Cells and is a full-service provider of environmentally advanced power solutions. With more than 40 years of experience, UTC Power is a world leader in developing and producing fuel cells for onsite power, transportation and spaceflight applications.

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Mr. Kent R. McCord, DGCP, is an assistant product manager with UTC Power, a United Technologies Corporation, located in South Windsor, CT. UTC Power is a world leader in developing and producing fuel cells for on-site power, transportation, space and defense applications, and a developer of other innovative combined cooling, heating and power (CCHP) applications in the distributed energy market. Mr. McCord may be reached via e-mail at kent.mccord@utcpower.com.