Caterpillar Combines Fuel Cells and Natural Gas Generator Sets In Hybrid Power Plants

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Overview

Fuel cells, those mysterious black boxes that always seem to be just over the horizon, are here now. Prices are dropping, efficiencies are rising, and assembly-line production capacity stands ready. Prospective users can now pick up the telephone and obtain a complete turnkey quote for a fuel cell-based power plant.

Fuel cells provide a host of advantages, including near-zero emissions, quiet operation and simple maintenance. As compelling as these advantages are, they pale in comparison to the tremendous efficiency offered by fuel cells. Molten carbonate fuel cells in the 1 MW class could run at 49% plant efficiency – better than the 37% efficiency typical of 1800 rpm reciprocating engine plants in the same size range. These efficiency numbers are based on lower heating value net of all plant parasitic loads.

A high efficiency molten carbonate fuel cell is a superior hedge against fuel price swings caused by regulatory turmoil, corporate instability and the usual market forces.

Yet for all their advantages, fuel cells have their limitations. Plant managers and experienced boiler operators raise an eyebrow when they hear that carbonate fuel cells take 72 hours to ramp up to full load from a cold start. Load changes also take much longer for a carbonate fuel cell than for a reciprocating engine. Fuel cells first installed cost is higher than engines and turbines on dollars-per-kW basis. High efficiency makes fuel cells well suited for baseload operation, but poor for shorter hour peaking and load-following applications. How then can fuel cells work in real world industrial plants, colleges, hospitals or municipal utility districts where electric loads erratically rise and fall?

One option is to combine a fuel cell and a gas-fired, engine-driven generator set (gas generator) into a hybrid plant. The natural gas fired fuel cell carries the base load, while a nimble gas generator set follows the peaks. Each prime mover plays to its strengths. The fuel cell perks along at its best efficiency point, undisturbed by load swings. The gas generator set carries the peaks and load changes.

Caterpillar and FuelCell Energy Inc. form Joint Development Agreement

Caterpillar and FuelCell Energy, Inc. (FuelCell Energy) of Danbury, Connecticut, have joined forces to offer integrated, custom-engineered hybrid plants on a turnkey basis. FuelCell Energy, Inc. (NASDAC symbol FCEL) is a world-recognized leader in the development and commercialization of high efficiency fuel cells for electric power generation. FuelCell Energy has been developing fuel cells for stationary power plants with the U.S. Department of Energy and the U.S. Department of Defense.

For more than 75 years, Caterpillar Inc. has been building the world's infrastructure and, in partnership with its worldwide dealer network, is driving positive and sustainable change in every continent. With 2002 sales and revenues of $20.15 billion, Caterpillar is a technology leader and the world's leading manufacturer of construction and mining equipment, clean diesel and natural gas engines and industrial gas turbines.

From a customer's perspective, the Caterpillar and FuelCell Energy joint initiative launches fuel cell technology into the real world of competitive, bankable projects. Caterpillar can provide hybrid plants on a full turnkey basis, with industry-standard terms and conditions, comprehensive warranty, and backed by the Cat dealer service network and worldwide reputation for excellence. The fuel cells are provided by FuelCell Energy. The gas generator set, auxiliary equipment, controls, erection, commissioning and service are all provided by Caterpillar.

Cat dealers can provide complete proposals for hybrid power plants in the 3 to 7 MW size range -- perfect for hospitals, universities and industrial facilities that are considering distributed-generation as a means of controlling their energy costs for consistent, reliable electricity supply.

The base hybrid configuration is a 1 MW fuel cell plus a 2 MW gas generator set, both using natural gas fuel. The fuel cell provides 1 MW of baseload generation, and the gas generator set provides 2 MW of peaking capacity, for a total of 3 MW. Any number of fuel cells and gas generator sets can be combined to fit a particular load. The remainder of this paper deals specifically with hybrid plants based on the following equipment:

- Single or multiple fuel cells, FuelCell Energy model DFC 1500, rated at 1 MW
- Single or multiple gas-fired, engine-driven generator sets, Cat model G3520C, rated at 2 MW
- Switchgear and controls
- Auxiliary equipment

What Is a Fuel Cell?

For starters, think of a fuel cell as a black box that consumes natural gas and produces useful electricity and usable waste heat. The black box also consumes a limited amount of potable water, and produces a plume of water vapor and a stream of processed liquid water. The inside of the black box looks a bit like a battery, with stacks of anodes and cathodes surrounded by carbonate electrolyte. Absent are moving parts and any sort of combustion process.

Today's fuel cells are broadly classified into 5 types: Alkaline, Proton-Exchange Membrane, Phosphoric Acid, Solid Oxide and Molten Carbonate. The FuelCell Energy design is a molten carbonate type, so named because it uses a carbonate material mixture as an electrolyte. Molten carbonate fuel cells, and notably the FuelCell Energy design, feature high efficiency and low emissions.

All fuel cells operate on pure hydrogen fuel. Typically, an external device called a reformer is used to strip hydrogen from natural gas. By contrast, the FuelCell Energy design uses a more efficient internal reformer that is directly integrated into the fuel cell process. This direct reformer feature is a key advantage of the FuelCell Energy design, hence the "DFC" (direct fuel cell) designation in the fuel cell model numbers.

Catalysts, anodes and cathodes within the fuel cell then ionize the hydrogen in a series of electrochemical reactions. This liberates electrons which produce electric current. A static inverter converts this direct current into standard 480 V alternating current. The static inverter is familiar and proven technology. Aside from operating software, the inverter is almost identical to the variable frequency drives used in elevators, light-rail car motors, and large industrial pumps and fans. The static inverter provides the added benefit of precision, widely adjustable, power factor control.

A fuel cell plant also includes the auxiliary systems listed below, largely consisting of off-the-shelf pumps, filters, controls and other components that are very familiar to plant engineers and operators.

Auxiliary System	Description
Fuel Filtering	Skid mounted system including standard off-the-shelf cartridge filters and activated carbon beds.
Water Treatment	Pre-packaged, skid-mounted reverse osmosis system consisting of off-the-shelf membranes, pumps and controls.
Startup Heater	Semi-portable gas heater with blowers and controls, used for pre-heating fuel cell during startup.
Instrument Air	Pre-packaged, skid-mounted dual air compressors with receiver, dryers and controls.
Static Inverter	Uses standard inverter technology of the sort used for variable frequency drives in electric trains and elevators. Unit is pre-packaged in a weatherproof enclosure.
Nitrogen Blanket	Refillable nitrogen bottles with regulator and controls, used to blanket the fuel cell internals during emergency shutdowns.
Fuel Preconverter	Compact skid-mounted system to convert higher hydrocarbons (propane etc.) in natural gas to methane.
Control Center and Switchgear	Standard industrial switchgear
Heat Recovery Unit	Compact heat exchanger installed in exhaust stack to recover heat necessary for fuel cell process.
Control System	Industrial control package based on Distributed Control System and Programmable Logic Controllers.

The carbonate electrolyte is a mixture of potassium carbonate (K_2CO_3) and lithium carbonate (Li_2CO_3). At room temperature the electrolyte exists as a solid, thus precluding any leakage or spillage during construction or maintenance. At the end of its useful life, the entire fuel cell core is sent to a recycler for recovery of all reusable material.

At fuel cell operating temperature, the electrolyte exists in semi-liquid gel form, closely held to the fuel cell internals by capillary action with minimal potential for leakage. Although mildly corrosive, the electrolyte never needs to be drained, changed or topped off.

Physically, a fuel cell power plant is a collection of quiet skid mounted industrial equipment, as shown in the picture below. The cylindrical vessel houses the actual fuel cell.

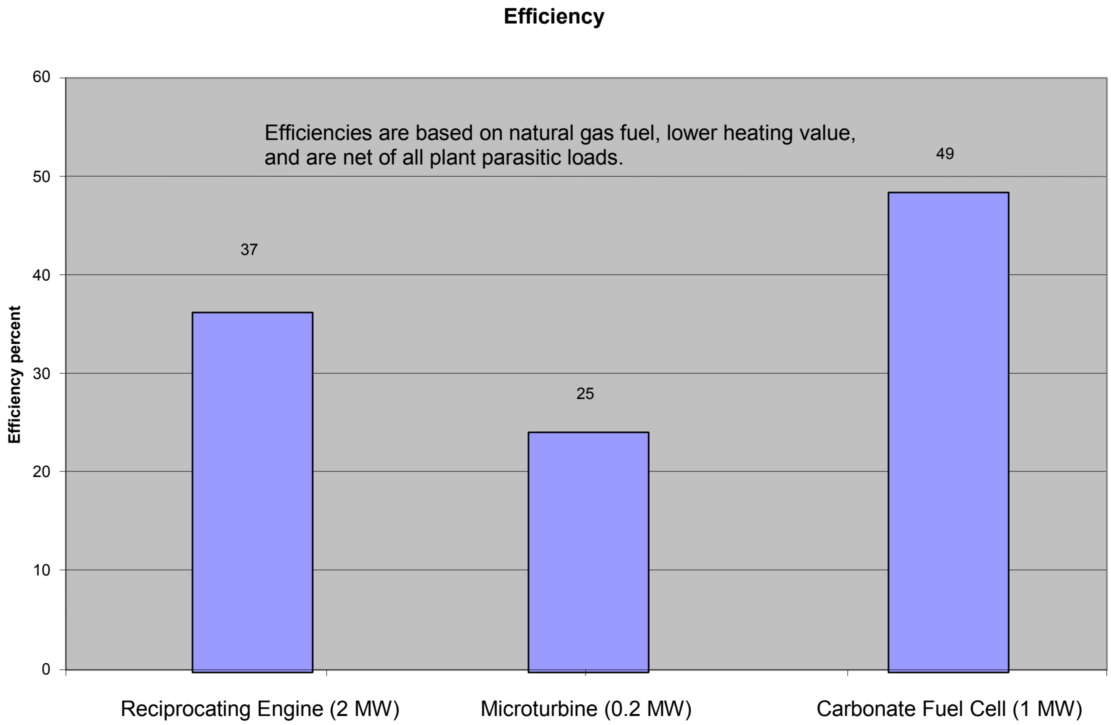
Fuel Cell History

Fuel cells were invented during the Industrial Revolution of the 19th century by a British judge and scientist, Sir William Robert Grove, in 1839. To put that date in perspective, it was more than 50 years *later* that Rudolf Diesel invented the diesel engine, finally obtaining his patent in 1893. The first practical use of fuel cells was by NASA in the 1960s during the early space missions. NASA needed a clean, ultra-reliable power source for Apollo spacecraft, and fuel cells were the best solution. Fuel cells have flown over 100 missions and logged over 80,000 hours in NASA spacecraft. The US Navy has used fuel cells in submarines since the 1980s. Intensive fuel cell development continues today as manufacturers strive to produce fuel cell based cars and power plants.

The molten carbonate fuel cells offered by FuelCell Energy are a modern embodiment of a very old, established technology.

Fuel Cell Efficiency

When it comes to efficiency in the 1 MW size range, fuel cells really shine when compared to other existing technologies such as reciprocating engines, gas turbines and microturbines. As shown in the graph below, the DFC 1500 fuel cell provides 49% electrical efficiency. The next-best technology, natural gas fueled reciprocating engines from Caterpillar, make a strong showing at 37% electrical efficiency assuming 1800 rpm. Microturbine efficiency is the lowest at approximately 25%.



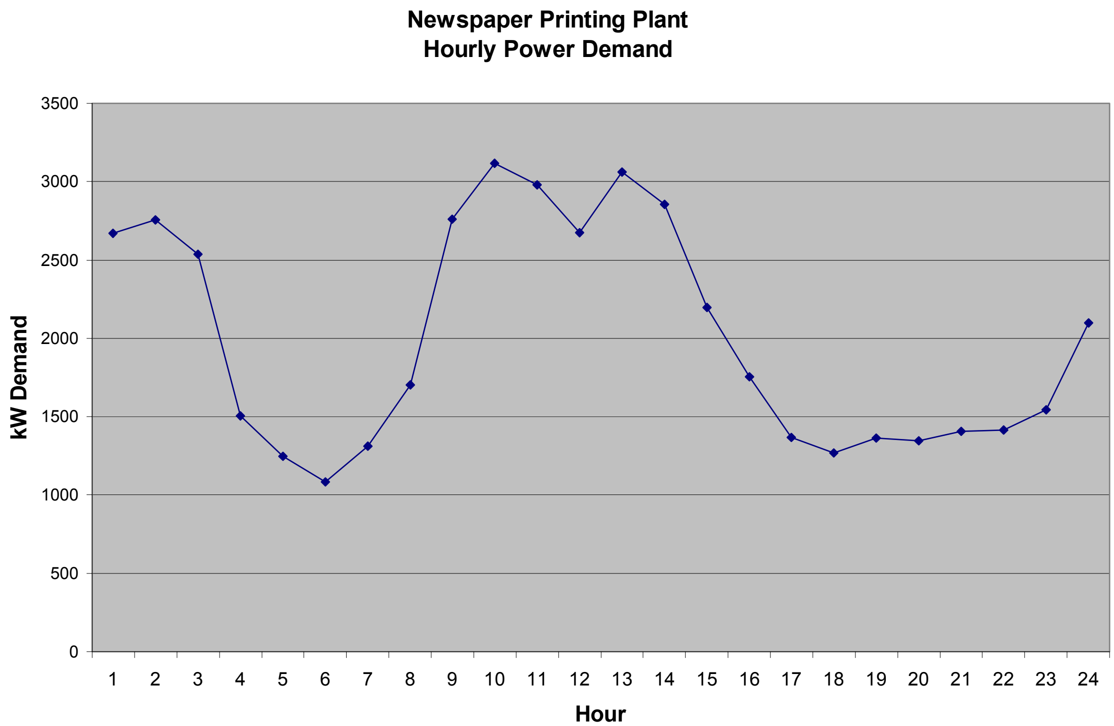
Fuel cells can be fitted with heat recovery equipment for combined heat and power (CHP) applications. With a respectable 650 °F exhaust temperature, fuel cells can produce hot water or saturated steam for process use. For example, the waste heat from a 1 MW fuel cell can generate approximately 1.4 MMBtu/hr of hot water suitable for space heating, water heating, process drying, absorption chilling or other process use.

At 49% net electrical efficiency, fuel cells are in the same efficiency range as the most efficient gas-fired plants on the utility grid, notably the newer 350 MW class combined cycle turbine plants. This allows fuel cells to compete, on a variable cost basis, in the world of real-time power pricing. High efficiency also mitigates high gas cost in areas where geographical isolation, pipeline tariffs, local taxes or fees drive natural gas prices up.

Fuel cells emit less carbon dioxide per kWh than gas fired engines or microturbines. Carbon dioxide emissions are inversely proportional to efficiency. Fuel cells consume less fuel per kWh than gas fired engines or microturbines and therefore produce correspondingly less carbon dioxide. Carbon dioxide is a greenhouse gas that has been implicated in global warming.

Typical Hybrid Plant Application

Where might a hybrid plant excel? As an example, consider a newspaper printing plant. The electric load curve below is derived from actual data from a major metropolitan daily newspaper.



During normal business hours the load is typical of commercial facilities, rising through the morning hours as employees arrive at work, dipping down for the lunch break, and then tapering off as the work day ends. Another peak appears in the pre-dawn hours when the printing presses are rolling to produce the morning edition. Underneath the peaks is a steady 1 MW base load that represents lighting, ventilation and incidental process loads.

In this case, a hybrid plant consisting of a 1 MW FuelCell Energy fuel cell and a 2 MW Cat G3520C gas generator set is an excellent fit. The fuel cell could serve the 1 MW base load with superb fuel efficiency and near-zero emissions – important to an industrial plant that already has a host of existing air permits to worry about.

A 2 MW Cat gas generator set would serve the peak loads during the day when power prices are highest. This gas generator set would run between roughly 8:00 a.m. and 3:00 p.m. in automatic load-following mode. Optional, readily available control software would constantly analyze power and fuel prices and decide, in real time, whether to make or buy power. The gas generator set would be automatically dispatched accordingly. The part-time, part-load operating regime would keep maintenance costs low. Substantial savings would accrue as the gas generator set displaced the highest retail power prices each day.

Most likely, it would be most economical to buy power during the pre-dawn peak, when power prices are low, rather than run the gas generator set.

The Cat G3520C can change load or stop almost instantaneously while the unit is on line. When emergency conditions occur, the Cat G3520C can start cold within 15-25 seconds, depending on temperature and other conditions. A normal cold start takes only a couple of minutes. The G3520C excels at load following, while maintaining high thermal efficiency and low NOx emissions.

The hybrid plant would also provide robust voltage support on site, thus eliminating chronic voltage sags and power factor problems that are so typical in urban industrial areas where aging substations struggle to support ever-increasing loads. The gas generator set uses an advanced generator control system to provide excellent voltage support, power factor control and VAR support. Normally both the gas generator set and the fuel cell would operate in parallel with the utility, but could also run in island mode. The gas generator set would provide black start capability.

The fuel cell, by virtue of its static inverter, does an excellent job of voltage support when combined with the gas generator set. This is because the inverter individually creates a voltage sine wave for each of the three phases, with a resolution of approximately 2,000 pulses per second, leading to a very smooth sine wave and high power quality. When the static inverter (of the fuel cell) is combined with the gas generator through the advanced Caterpillar control system, the result is a highly advanced power generator with unprecedented ease of operation and control, more precise control of power factor and VARS, as well as excellent load following capability.

The newspaper would also enjoy several intangible benefits from a hybrid plant. The two separate generating units in a hybrid plant provide more reliability than would a single turbine or engine. Government incentives would likely cover part of the capital and/or operating costs. The public relations value of a fuel cell is outstanding, and fosters favorable advertising, annual reports, press releases and public tours. And finally, the printing plant would no longer suffer from motor burnouts and control system crashes caused by recurring voltage sags.

Neighbors and local activists who oppose a traditional engine power plant might support a hybrid plant because fuel cells are perceived as safe green power. More concretely, the hybrid plant produces far less exhaust emissions, uses much lower pressure gas, produces less greenhouse gas, and operates more efficiently. Environmental groups that traditionally take a neutral or adversarial position with gas turbines may actually embrace a hybrid plant.

When power prices again spike to 20 or 30 cents per kWh or higher, due to regulatory chaos or economic pressures, the hybrid plant could pay for itself in a few seasons while keeping the presses running through any brownouts or utility transmission failures.

Niche Markets for Hybrid Plants

Utilities and Municipal Utility Districts are looking at fuel cells as environmentally conscious customers request the option to buy green power. For example, in March of 2003, the Los Angeles Department of Water and Power commissioned a 250 kW FuelCell Energy fuel cell power plant, partly in order to add more green power to their generation mix. Ratepayer demand for green power is rising. According to a recent study by the National Renewable Energy Laboratory, 350,000 U.S. households have already elected to buy green power[i].

Fuel cells are also ideal for applications where reliability is essential, such as remote cellular phone sites, airports or military bases. In May of 2003, a 250 kW FuelCell Energy power plant was commissioned at a Coast Guard Air Station on Cape Cod where reliability can't be compromised. An additional benefit for this customer was funding provided by the Massachusetts Renewable Energy Trust Fund which paid a significant portion of the costs.

Fuel Cell Emissions

Negligible. That is the word that best describes molten carbonate fuel cell emissions. Strictly speaking, fuel cells do emit tiny amounts of exhaust emissions. From a practical point of view however, FuelCell Energy fuel cells are zero-emission devices. Consider a few examples to illustrate the point.

- A fuel cell started on New Years day could run flat out until the Fourth of July, and still produce less NOx than any same-size gas generator set produces in a *single day* (assuming a state-of-the-art gas generator set that produces 0.5 grams of NOx per horsepower hour, without additional external control such as Selective Catalytic Reduction (SCR)).
- In Los Angeles, one of the strictest permitting agencies in the country, the South Coast Air Quality Management District, has ruled that fuel cells *do not need an air permit* at all (reference SCAQMD Rule 219, available online).
- In a hybrid plant consisting of a 1 MW fuel cell and 2 MW gas generator set (without SCR), the fuel cell contributes less than ½ percent of the total NOx. In other words, the fuel cell NOx emissions essentially disappear into round-off error.
- Air quality regulations are customarily written in terms of *tons* per year of emissions, yet a 1 MW fuel cell produces less than *7 pounds* of SOx per year.

Why are fuel cells so clean? In microturbines and reciprocating engines, NOx forms when atmospheric nitrogen is heated to combustion temperatures. Since there is no combustion in a fuel cell, and the process runs at much cooler temperatures than combustion devices, NOx production is essentially zero. Fuel cell SOx emissions are ultra low simply because the required fuel treatment systems strip sulfur out of the natural gas before the gas enters the fuel cell itself.

Because there is no combustion in a fuel cell, the emission rates for particulates, CO and unburned hydrocarbons are also negligible as shown in the table below.

Fuel Cell Emissions Model DFC 1500 rated 1 MW		
	lbs/MW-hr	lbs/year
NOx (as NO2)	0.006	56
SO2	0.0002	7
CO	0.001	28
NMOC	0.033	140
Particulates	0.0058	77

Natural Gas Generator Set Emissions

With state-of-the-art lean burn technology, and an active control system that senses detonation in each cylinder, the Cat G3520C produces just 0.5 grams of NOx per horsepower hour. This low NOx emission rate matches or beats the NOx performance of any comparably sized engine-generator in the world.

Gas Generator Set Emissions Cat G3520C rated 2 MW			
	lbs/MW-hr	lbs/hr	Tons/year
NOx (as NO2)	1.5	3.0	13.2
CO	6.3	12.7	55.5
NMOC	2.2	4.4	19.3
Note: Cat G3520C operating at 1,800 rpm and 0.5 gram/hp-hr NOx			

From an air permitting perspective, the fuel cell and the Cat gas generator set will probably be treated separately even though located on the same site. The fuel cell, with nearly zero emissions, will likely skate through permitting with either an outright exemption, or a very liberal permit that allows unlimited operating hours. This lets the fuel cell do what it does best – run at full power 24 hours a day, 7 days a week.

The gas generator set does produce some exhaust emissions, though at a very low rate of about 0.5 grams of NOx per horsepower hour. Every hour of operation adds exhaust emissions to a running total that could trigger a regulatory mandate for SCR or other mitigation measures. As a practical matter, either the applicant or the permitting agency may limit gas generator set annual operating hours in order to stay under a regulatory trigger point. Fortunately such limits still let the gas generator set do what it does best – run during peak periods in load-following mode when power prices are highest.

In many locations, the gas generator set can be permitted without restrictions on operating hours, and this is the preferred scenario. However, any reasonable air permit restrictions of annual operating hours are unlikely to curtail the gas generator set in practice. This is because the fuel cell carries the baseload, and the gas generator set just carries the peak loads during certain times of the day when power prices are high.

Performance Data

Performance data for the DFC 1500 fuel cell, Cat G3520C gas generator set, and combined hybrid plant are shown below.

Hybrid Plant Performance			
	Fuel Cell	**Cat G3520C Generator Set**	**Combined**
Net Power (MW)	1.0	2.0	3.0
Efficiency (LHV, net of parasitic load)	49%	37%	45%
Exhaust Temperature (°F)	650	893	n/a
Exhaust Flow (lb/hr)	13,800	17,348	n/a
Note: Cat G3520C operating at 1,800 rpm and 0.5 gram/hp-hr Nox			

Economics

Capital cost is still high for fuel cells, though falling fast. Current fuel cell installed costs are in the $4,200/kW range for a complete 1 MW unit. Installed cost for a Cat G3520C gen set is, however, about $400 to $600 per kW, so the capital cost of a hybrid plant is about $1,800 per installed kW, or much less when available state and Federal incentives are applied. Eligible costs include engineering, equipment, construction, commissioning, and debt service.

Assuming fuel costs at $4.00 MMBtu, the fuel cell can generate power at 13ct/kWh. The gas generator can generate power at 6ct/kWh for a blended hybrid plant rate of

8.9ct/kWh. This includes expense for operations labor, maintenance, overhauls, fuel, consumables, debt service and utilities.

By virtue of ultra-low emissions and superior efficiency, fuel cells also qualify for most of the "green power" incentives and subsidies available from government agencies and utilities. Often these incentives are in the $2,000/kW range. Yet regardless of incentives, a hybrid plant may be the best distributed generation solution when one or more of the following conditions exist:

- No other technology can meet air permit requirements
- Municipal Utility Districts, Co-Ops or Utilities want to offer customers the option of buying green power
- Sophisticated environmental groups block conventional engines and turbines during the permit process
- An existing cogeneration plant is replaced, thus releasing emissions offsets for profitable sale
- Blackouts, brownouts and voltage sags are common
- Gas pipeline restrictions limit the quantity of gas that can be delivered, thus favoring high-efficiency systems that can make more power from the available gas
- Electricity costs are high
- There is a corporate or community commitment to green power
- Baseline electric load is steady, but peaking loads fluctuate widely

Plant Footprint

A 1 MW fuel cell plant occupies less than 3,000 square feet, including maintenance access and laydown space. All equipment is skid mounted, deliverable by truck, and designed for outdoor installation. Likewise, the 2 MW Cat G3520C gas generator set is pre-packaged on a single skid with a weatherproof enclosure. The entire 3 MW hybrid plant easily fits in 5,000 square feet.

Where space is at a premium, the fuel cell and gas generator set can be mounted a short distance apart from each other. Noise from the fuel cell is minimal (70 dbA at 10 feet), and roughly equivalent to average street noise. Hence, the fuel cell can be located close to public areas, sidewalks and houses. In a hospital or university setting for example the fuel cell could occupy landscaped space at the front or side of a public building, behind a simple architectural screen in areas never before deemed usable for generation.

Required natural gas pressure is 15 psig for the fuel cell, and 0.5 to 5 psig for the Cat gas generator set. Most local gas lines can supply 15 psig, which means that many hybrid plants will not need gas compressors.

Operations

Fuel cells are designed for unattended operation. A local control panel is provided along with options for remote operation from a control room and/or from a remote location via a dial-up connection. Operations labor requirements are minimal, consisting of periodic inspections, minor adjustments and lubrication of auxiliary motors, pumps and fans.

A 1 MW fuel cell requires 160 gph of potable water, which passes through a reverse-osmosis purification system prior to use in the fuel cell. The purified water participates in the fuel cell reactions and ultimately exits to atmosphere via the exhaust stack. Approximately 65 gph exits as wastewater (reverse osmosis processed water) for discharge to sewer or gray water system. Aside from high mineral content, the wastewater is clear and suitable for use as rinse water for produce cleaning, makeup to decorative fountains, factory washdown water and other gray water uses. A balance of exothermic and endothermic reactions in the fuel cell provides all necessary cooling so no cooling tower or other cooling water source is required.

Other consumables include cartridge filters, miscellaneous lubricants and bottled nitrogen used for purging the entire fuel cell gas flow path during startups and emergency shutdowns, as required. Activated carbon is also used in the natural gas filtering system. This carbon must be replaced at approximately 6-month intervals, but will depend on odorant levels in the fuel. A single ton of activated carbon generally suffices for a year of full-load operation.

The Cat G3520C is also designed for unattended operation. A full-time onsite operator may be required if the hybrid plant includes waste heat recovery and the associated heat recovery steam generators.

Fuel Cell Maintenance

Aside from auxiliary fuel and water systems, fuel cells have no moving parts. Major maintenance is therefore simpler. Fuel cell maintenance boils down to three R's – Remove, Replace and Recycle the parts that wear out.

Fuel cells have a predictable wear pattern. Though power quality remains constant over the service life of the product, power output and efficiency degrade slowly and predictably over time. At a point typically defined by project economics, the core of the fuel cell is removed for recycling and replaced with a new core. In industry parlance, this replaceable core is called a stack because it consists of alternating layers of cells, each containing an anode, a cathode and an electrolyte substrate.

Indulging now in a bit of over-simplification, think of a stack replacement as similar to replacing a large rechargeable battery pack. A stack replacement is fundamentally a much more simple operation than rebuilding an engine or turbine. See the table below for a schedule of major Remove-Replace-Recycle items.

Fuel Cell Maintenance Schedule		
Item	**Quantity**	**Replacement Interval**
Fuel cell stack	Unit	3 years for first replacement, 5 years thereafter
Heat recovery catalyst	13 cubic feet	2 years
Preconverter catalyst	4 cubic feet	3 years
Deoxidizer catalyst	1 cubic foot	5 years
Anode exhaust catalyst	4 cubic feet	5 years

The DFC 1500 is really a 1.5 MW unit that carries a conservative introductory rating of 1 MW. The first stack replacement is scheduled to occur after 3 years of continuous operation, when nominal electrical degradation is expected to reach 10%. This 10% value is the sum of power output degradation and efficiency degradation (e.g. 7% power degradation plus 3% efficiency degradation). Economic calculations will determine the optimum stack replacement interval, but 3 years is a good nominal time for the first replacement.

Over time the DFC1500 electrical rating will be increased to the full 1.5 MW, and the stack replacement interval will be 5 years instead of 3. This 50% power upgrade should be kept in mind when evaluating capital costs.

Fuel cells have no generator in the classical sense. Instead a large static inverter converts DC output from the fuel cells to standard 480 Volt AC power at 60 Hertz. This inverter is a static device nearly identical to the variable speed drives commonly used for large pumps and fans, and has proven to be a low maintenance item.

Cat Dealers offer a variety of maintenance agreements, ranging from simple parts-only agreements, to a comprehensive agreement that includes all scheduled and unscheduled maintenance as well as complete stack replacement. Comprehensive agreements are of particular benefit for the fuel cell portion of the plant, which is likely to be less familiar to a customer's experience base.

Comprehensive maintenance agreements are also available for the Cat gas generator sets. However, because gas generator sets are such a well-established technology, a customer may elect instead to use in-house staff to maintain the gas generator set. Customers are free to mix and match maintenance agreements, perhaps relying more on Caterpillar for the fuel cell maintenance, and less for the gas generator set and balance of plant. In any case the full network of Caterpillar dealers and service centers stands behind the equipment.

Both the gas generator sets and the fuel cells are engineered, designed and assembled in the United States.

Caterpillar Provides Complete Solutions

Interested in a hybrid plant? Caterpillar engineers will analyze a customer's historic energy consumption and costs, and propose a plant configuration that optimizes economic return and operational benefits. Caterpillar will then submit a turnkey proposal based on customary terms and conditions, and backed by the Caterpillar service network. If desired, Caterpillar can also provide complete operating and/or maintenance services for the life of the plant.

Caterpillar can also provide a variety of project financing options ranging from low-interest loans to complete leasing packages. On a selective basis, Cat may develop, own and operate a hybrid plant, and sell power (and in some cases steam and/or chilled water) to the host facility under a long-term energy supply agreement.

For parts, service and warranty support, Caterpillar is a customer's single point of contact for both the fuel cells and the gas generator sets.

Conclusion

The low emissions and high efficiency offered by fuel cells are so compelling that governments and auto makers worldwide are pumping billions of dollars into fuel cell development. As fuel cell prices fall, hybrid power plants will command an ever-increasing share of the distributed generation market.

A Caterpillar and FuelCell Energy hybrid power plant provides a viable alternative to distributed generation engine or turbine power plants. Forward-thinking businessmen, engineers and developers will reap early rewards as the first hybrid plants come on line.

(Sidebar #1)
Why are Fuel Cells so Efficient?

In the 19th century, a French engineer named Nicolas Carnot discovered that high temperature is the key to high efficiency in any heat engine (heat engines include most conventional power generating equipment, such as combustion turbines, reciprocating engines, and conventional boiler/steam turbine power plants). Simply stated, high efficiency can only be achieved at high operating temperatures – the hotter an engine runs, the more efficient it can be. Unfortunately, real-world machinery cannot endure ultra-high temperatures. Hence even the most modern heat engines, built with the best heat-resistant alloys, face practical efficiency limits.

Not so with fuel cells that are not heat engines at all. Fuel cells are electrochemical devices, roughly akin to batteries.

Fuel cells are already the most efficient technology in the 1 MW size range, and are poised to become even more efficient in the years ahead.

Nine Things to Know About Fuel Cells

1. Fuel cell efficiency is 49%, compared to roughly 37% for reciprocating gas generator sets
2. Fuel cells produce almost no exhaust emissions
3. It is ok to think of a fuel cell as a black box, and not understand the electrochemistry that goes on inside
4. Fuel cells are quiet
5. Waste heat from fuel cells is easily recovered for use as process steam
6. Fuel cell prices are falling fast
7. People who ignore fuel cells now will have to catch up later
8. Everybody likes fuel cells – politicians, local officials, newspaper reporters, environmental groups, civic groups and voters
9. Caterpillar now offers turnkey hybrid plants backed by the Caterpillar service network

About the Author

Chuck Loos, P.E., is President of Columbia Power Consulting based in Oregon. With 24 years of experience in the independent power industry, Chuck offers clients deep skills in engineering, project development, environmental permitting and due diligence. Throughout his career, he has focused on reciprocating engines and gas turbines in cogeneration applications. Chuck has held senior-level engineering management positions at three power development companies, as well as field management positions in plant startup and operations. Contact Chuck at (503) 842-3246.

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[i] *Forecasting the Growth of Green Power Markets in the United States*, National Renewable Energy Laboratory, October 2001