# Assessment of Packaged PEM Fuel Cell CHP Systems

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ABSTRACT

Packaged fuel cell systems are technically attractive for distributed generation because they are very efficient, quiet, and have the potential for very low waste-stream emissions. Packaged fuel cell systems have been commercially available for about 10 years. Although still expensive, the cost, reliability, and performance of these systems have been improving steadily. This document describes the technology, its application niche, and what a potential user needs to consider when making procurement decisions.

## WHY COMBINED HEAT AND POWER (CHP) DISTRIBUTED GENERATION (DG)?

The motivations for distributed power stem from our increasing reliance on electrical devices, from the high costs of expanding central generation capacity and transmission and distribution (T&D) capacity, and from the technical barriers to using central plant waste heat effectively. By adding distributed generation instead of central plant capacity, the need to expand T&D capacity is reduced or eliminated. By situating DG at facilities where waste heat can be put to good economic use (the premise of CHP), the prohibitive costs and inefficiencies of heat transmission are avoided. In some applications, the primary motivation is power reliability; the redundancy inherent in grid-connected DG achieves this objective.

## TECHNOLOGY DESCRIPTION

Fuel cell development for transport and DG applications has increased remarkably in the past decade. There are a number of fuel cell technologies that appear to be viable in one or more applications, as indicated in Table 1. Note that the proton exchange membrane (PEM) technology, at its current stage of development, has the best efficiency and power density of all the technologies that run on air at low temperature. High temperature, such as with the molten carbonate fuel cell (MCFC) and the solid oxide fuel cell (SOFC), and pure $O_2$, such as with the alkaline fuel cell (AFC), are considered safety concerns.

The fuel cell CHP systems demonstrated at Fort McPherson in Atlanta, Georgia, and at the 4th District U.S. Coast Guard Station, New Orleans, Louisiana,* are built around one main package that houses a fuel processor, PEM cell stack, power conditioning, recovery heat exchanger, and controls (all discussed below). An additional heat exchanger and pump may be required in the facility that will use the recovered heat. In most cases, an external water treatment unit is also required.

**PEM Cell Stack**

The proton exchange membrane (PEM) fuel cell uses a polymer electrolyte in the form of a thin sheet or membrane. The PEM blocks electrons but allows positive ions preferentially (more protons than electrons) to pass, as shown in Figure 1. Hydrogen is supplied at the anode and air is supplied to the cathode. A platinum catalyst promotes electrolytic reaction at the cathode.

The half-reaction at the anode (-) is:
$2H_2 \rightarrow 4H^+ + 4e^-$
The half-reaction at the cathode (+) is:
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Each cell generates 0.7 volts and a stack of 70 cells in series is used

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*Fort McPherson was selected initially based on special interest by the Public Works Directorate of U.S. Army, Installation Management Agency, Southeast Regional Office. The Coast Guard site was added because it has significant heat load. The ESCO for both sites, LoganEnergy, agreed to provide access to the on-line performance data.

## Table 1. Summary of Technical Characteristics by Fuel Cell Type

| | **Phosphoric Acid Fuel Cell** | **Alkaline Fuel Cell** | **Molten Carbonate Fuel Cell** | **Solid Oxide Fuel Cell** | **Proton Exchange Membrane (PEM)** | **Direct Methanol Fuel Cell** |
|---|---|---|---|---|---|---|
| $T^{cell}$(°C) | 200 | 80 | 650 | 1000 | 90 | 80 |
| Efficiency* | 42% | 70% | 50% | 40% | 45% | 25% |
| Conducting Ion | $H^+$ | $OH^-$ | $CO_3^{2-}$ | $O_2^-$ | $H^+$ | $H^+$ |
| Cathode Gas | Atmospheric | Pure $O_2$ | Atmospheric | Atmospheric | Pure $O_2$ and Atmospheric | Atmospheric |
| Catalyst | Pt | Pt, Ni/NiOx | Ni/LiNiOx | Ni/Perovskites | Pt | Pt |
| Fuel | $H_2$ | $H_2$ | $H_2$ and $CH_4$ | $H_2$ and $CH_4$ | $H_2$ (pure or reformed) | $CH_3OH$ |
| Power Density | 220 mW/cm³ | 4000 mW/cm³ | 150 mW/cm³ | 240 mW/cm³ | 300 mW/cm³ | 20 mW/cm³ |
| Electro-Chemical Challenges | Hydrogen electro-catalysis, cathode corrosion | Hydrogen electro-catalysis, cathode corrosion | Oxygen electrode, cathode corrosion | Expensive component layers high temperature | Oxygen electro-catalysis, water management | Methanol electro-catalysis, anode poisoning |
| Application | Onsite cogeneration, transportation | Space Vehicles transportation | Power generation, cogeneration | Power generation, regenerative fuel cell | Transportation, space defense, standby power | Transportation, remote power, standby power |

*Electric only based on lower heating value of fuel, no inverter or reformer power penalties, under ideal conditions.

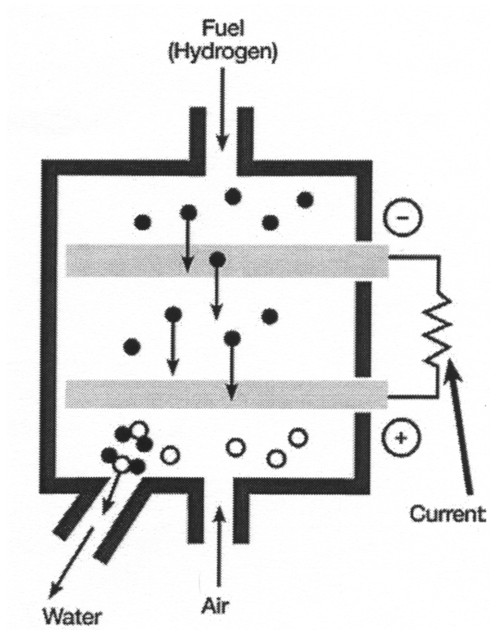


**Figure 1. PEM Fuel Cell**

to generate power at about 50 volts. Because the polymer softens with temperature, the stack is limited to 80°C (175°F). This makes the efficiencies of PEM fuel cells somewhat less than those of higher temperature technologies, such as solid oxide fuel cells (SOFC) and molten carbonate fuel cells.

**Reformer**

Two reactions convert steam ($H_2O$) and natural gas (mostly $CH_4$) into hydrogen and carbon-dioxide ($CO_2$). The first produces some hydrogen and carbon-monoxide (CO) as an intermediate product:

$CH_4 + H_2O \rightarrow CO + 3H_2$

The second reaction converts CO and steam to $CO_2$ and more hydrogen: $H_2O + CO \rightarrow CO_2 + H_2$

Residual $CH_4$ and residual CO are the two main perpetrators of cell stack poisoning.* Therefore, they are selectively burned ($CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ and $2CO + O_2 \rightarrow 2CO_2$) at low temperature in the presence

*Poisoning refers to accumulations of compounds that reduce the efficiency of cathode, anode, or electrolyte.

of a catalyst before entering the cell stack. This extends cell stack life.

Waste heat comes from the burning of residuals and from the cell stack reaction. With current practical implementations, the overall efficiency of natural gas to electrical conversion without heat recovery is less than 30%. Some of the conversion heat (e.g., inverter heat) is not easily recoverable. Even with heat recovery, the maximum overall efficiency for the demonstration unit (total of heat plus power) is about 65%.

**Inverter**

The inverter converts 48Vdc to 120/240Vac and provides the necessary grid interface (power-factor and frequency following control). An approved* transfer switch is built in—and two external connections, main power and emergency power, are provided. When main power fails, the inverter is disconnected from the main panel to prevent back feed but may continue to feed an emergency power subpanel with no interruption. Field installation requires only two simple disconnects—typically one of these, the emergency panel breaker—already exists. Some utilities may have special requirements for grid connected DG.

**Battery**

The battery stores enough energy to carry the machine through load fluctuations encountered during emergency load service (grid outage) or in off-grid operation and to start the machine (cold boot) without grid power. The battery is not used when the unit is operating at a fixed (electric kW output) set point. A battery life of 5 years or more can therefore be expected in installations that run mainly in grid-connected constant-set point mode.

**Controls and Utility Interface**

The utility interface has two modes, on-grid and off-grid. In on-grid mode, the inverter tracks utility frequency and supplies current in phase with utility voltage to maintain a predetermined or remotely adjustable fuel cell power output. The demonstration unit develops up to 5 kW continuous, but most units have been operated at 2.5 kW continuous. The best mode of operation is site-specific to strike a reasonable balance between rate of payback (best at around 4 kW) and stack life (decreases with increasing power level).

*Canadian Standards Association listing, which is recognized in the United States.

In off-grid mode, the inverter maintains voltage and frequency according to its internal references, and satisfies the real and reactive power of the aggregate local or emergency load by continuously adjusting the load. Time-varying control of capacity may be appropriate in off-grid installations.

**Water Supply and Discharge**

The reformer feed-stocks mentioned above are methane and water. Although the reformer and cell stoichiometry yield more water than is consumed, the current design requires a separate source of high purity water. Plug Power's purification unit uses a 3-step process: rust/scale filtering, reverse osmosis (RO), and ion exchange. Water requirements vary in directly with power output. At 2.5 kW, the PEM unit requires 50 gallons per day (gpd) of pure water and produces about 100 gpd of waste water. The water plant and feed line must be protected from freezing.

**Heat Recovery**

The reformer and fuel cell produce electricity from natural gas at 24% to 26% efficiency based on lower heating value (LHV) of the gas. Better overall efficiency can be obtained by making use of the 3.3 to 6.7 $kW_{thermal}$ of heating produced in the reformer and cell stack. In most CHP installations, the heat by-product is transferred to a domestic water heater or similar load, as shown in Figure 2. When the load is satisfied, tank temperature at the base of the dip tube will approach the fuel cell operating temperature (about 170°F). The heat by-product will then have to be discharged via waste water and ambient air, and overall efficiency will revert to the machine's efficiency as an electrical power source.

## CHARACTERISTICS OF DEMONSTRATION PACKAGE

A package that integrates the reformer, cell stack, heat recovery, battery, and inverter has been deployed at federal sites as part of a demonstration program. The product specifications of the package are documented in Appendix A.

The performance data are summarized in Table 2, and the PEM fuel cell in-place at Fort McPherson is pictured in Figure 3.

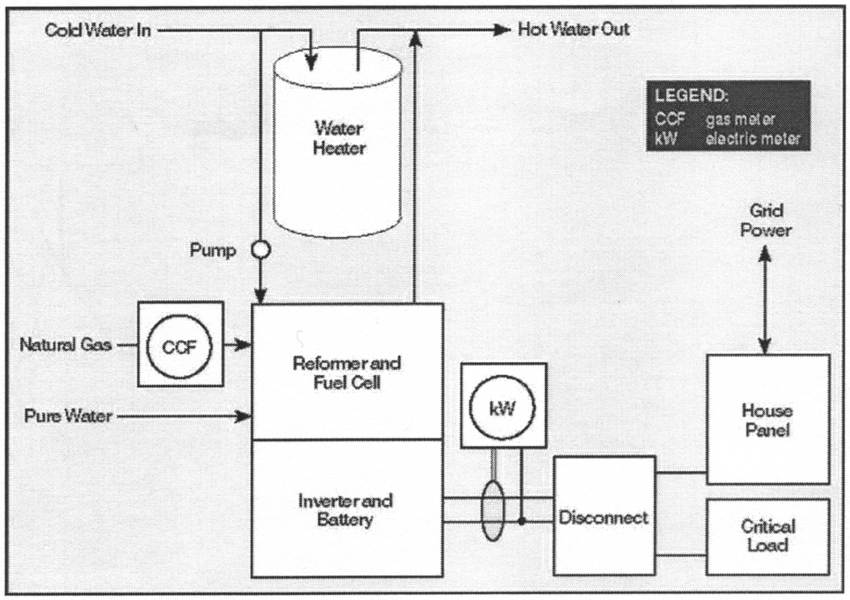


**Figure 2. High Level Combined Heat and Power Schematic.** ***Heat transport design is site-specific. A system with one pump and no heat exchanger is shown.***

**Table 2.**
**Performance Specifications for Federal Demonstration Package**

| **kWe set point** | **2.5** | **4** | **5** |
|---|---|---|---|
| Generation Efficiency (kWe/LHVkW) | 26 | 25 | 23.5 |
| Overall Efficiency ((kWe+kWth)/LHVkW) | 31.6 | 54.6 | 73 |
| Water Use (gallon/hr) | 3.33 | 5.67 | 7.33 |

Over twenty package fuel cell units of this type have been installed in the demonstration program as of January 1, 2005. Most of the demonstration sites produce heat as well as power. For the two demonstration sites reported here, the thermal output is used to heat domestic water and an intermediate loop carries ethylene glycol for freeze protection. A heat exchanger at the water heater transfers heat from the glycol loop to the

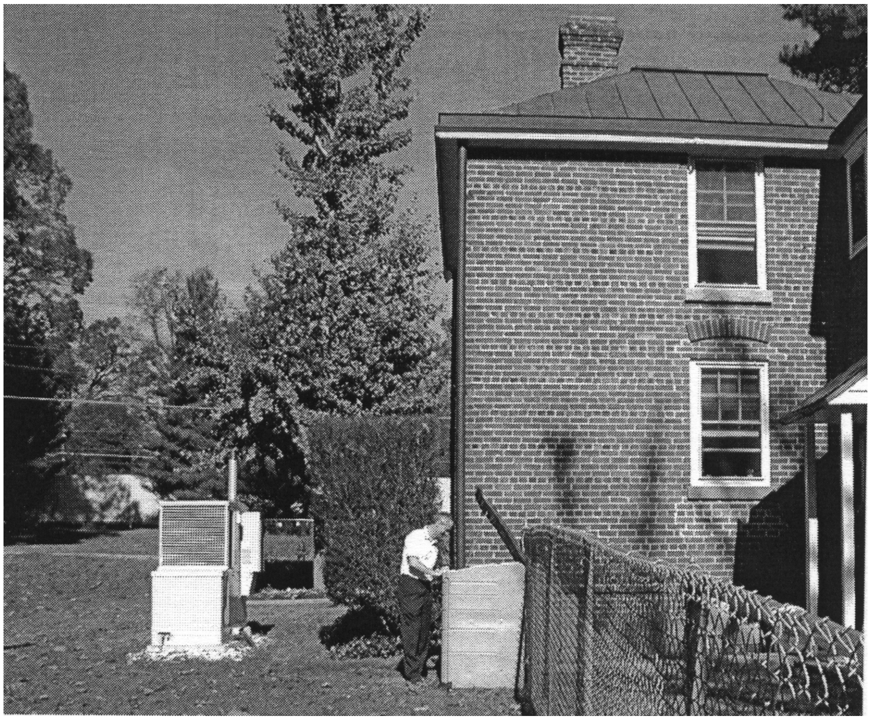

**Figure 3. Demonstration PEM Fuel Cell-based CHP unit (left) at Fort McPherson.**

potable water loop whenever heat is needed (potable water below 140°F) and available (fuel cell operating such that glycol loop temperature is greater than potable water temperature). In addition to a heat exchanger approved for potable water use, a differential temperature controller and two pumps are required to implement this heat recovery scheme. Excess heat is rejected to the waste water stream and to ambient air when the domestic water heating load is satisfied. Most of the demonstration units feed power to the grid during normal operation and keep emergency loads in operation when grid power fails. The characteristics of the products deployed in the demonstration program and the performance observed at two of the sites are described below.

**Operations and Maintenance**

The complexity of this technology could be said to lie between that of unitary HVAC equipment and that of an automobile. However, because the technology is less mature, the maintenance expectations are correspondingly higher. Although considerable design attention is devoted to ongoing improvements to reliability and simplicity of O&M, the user should be aware of the current basic maintenance needs.

**Batteries**: Batteries require no periodic maintenance. However, battery life is finite, depending largely on load magnitude and frequency of large load variations during off-grid operation. Replacement at roughly 5-year intervals can be expected at a cost of roughly $500.

**Air Filters**: Cathode air filters require replacement, typically every 12 months.

**Radiator**: Coolant flush and replacement service intervals are typically longer (>5 years) than for an automobile. Air side surfaces should be cleaned yearly or more often under dusty conditions (i.e., less often than for the outdoor unit of an air conditioner).

**Periodic stack replacement**: The fuel cell stack must be replaced every 7,000 to 10,000 operating hours. The cost of stack replacement is roughly $10,000 and is covered under the typical maintenance contract.

**Water supply**: The current design's requirement for very pure de-ionized (DI) water defines the most labor intensive elements of site maintenance. In hard water locations, a water softener, with its attendant maintenance requirements, is needed. All installations require an RO filter and a resin bead cartridge for ion-exchange. Service intervals for these items range from 1 to 4 months.

**Assessment Checklist**: Before investing in fuel cell technology, a buyer should carefully evaluate the costs and benefits. A representative cost analysis is presented in Appendix B. In addition, the following technical issues should be considered.

Load characteristics should correspond to DG/CHP capabilities:

- Peak electrical load and load factor
- Thermal load and load factor; thermal storage requirement, cost, space

Logistical support:

- O&M—understand required capability, commitment, and cost
- Training—buyer's technician must attend manufacturer's two-week training program
- Source of DI water—site must provide for warm water discharge
- Freeze protection—heat recovery loop and water supply must be protected.

Life-cycle cost—In remote and critical power applications, there are often several options or combinations of options for satisfying peak- and base-load load requirements. For each option, one must evaluate the following cost elements:

- Annual cost of fuel(s) and delivery thereof
- Annual cost of maintenance including cell stack renewal
- Annual value of displaced existing electrical and thermal source energy
- Amortized costs (equipment, installation, design, administration, commissioning)

**Acceptance Tests**: Before taking ownership of the CHP system, it is important that the owner confirm proper operation and performance. This activity is a good step in familiarizing local maintenance person(s) with the new technology and the monitoring equipment.

The monitoring equipment is essential to ongoing tracking of its operating condition and diagnosis of problems, should they occur. A basic acceptance protocol should include the following:

**Controls**: check responsiveness and calibration of sensors and actuators

**Capacity**: measure peak capacity for 1 hour

**Noise**: check fan noise and vibration

**Emissions**: check for $NO_x$ and CO

**Start-stop cycle**: demonstrate start-stop cycle and 8 hours continuous operation

**Leak check**: reformer, cell stack, water, heat rejection; all feed and discharge lines

**Efficiency**: measure gas input and kWh and Btu output for 8-hour run at planned capacity.

## DEMONSTRATION RESULTS

A large number of residential-scale PEM fuel cell installations have been made for the DOD Fuel Cell Demonstration Program (Binder, Taylor and Holcomb 2001). Two representative sites are at Fort McPherson, Atlanta, Georgia, and the 4th District Coast Guard Station (CGS), New Orleans, Louisiana. The demonstration sites were provided with basic performance verification metering consisting of residential-type gas and electric meters, as shown for Fort McPherson in Figure 4.

Heat recovery was measured at Fort McPherson using volumetric flow rate and temperature sensors. A programmable logic control system was configured to monitor and communicate the data to a server

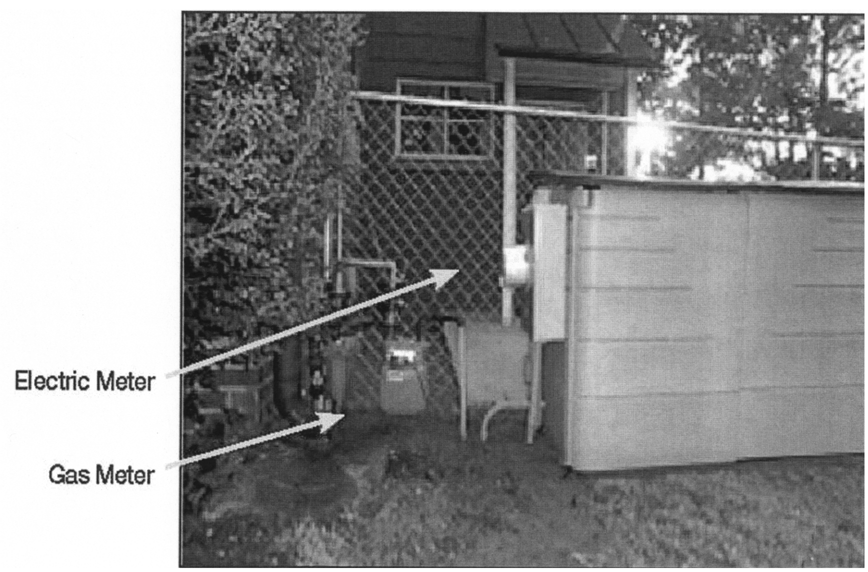


**Figure 4. Residential-type Meters to Record Gas Input and Electric Output.**

that provides web access to all stakeholders.

The Fort McPherson and CGS sites are both configured to provide constant electric power with any difference between the power set-point and local load being absorbed or supplied by the grid. Figure 5 shows that the electric power output at Fort McPherson in July 2004 was 2.5 ± 0.1 kW about 98% of the time. In grid independent mode, the fuel cell output is modulated to track the local emergency load. However, there were no grid outages to show during the July test period. Heat generated by the fuel cell and reformer is determined by the unit's electrical power output, not by the local thermal load. Any shortfall in heat output by the fuel cell unit is provided by auxiliary heat plant (domestic water heater) and any excess heat is dissipated to ambient via the waste water stream and/or the unit's cooling fan.

The thermal load at Fort McPherson turned out to be

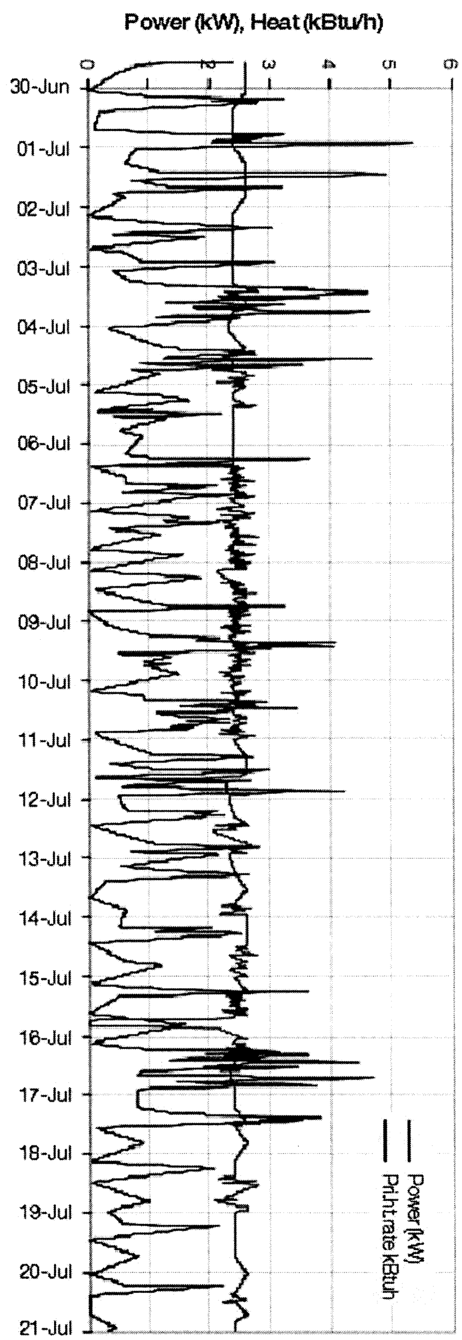


**Figure 5. Heat and Electric Power Output by Fort McPherson Demonstration Unit, July 2004.**

much smaller than the CHP capacity at even the lowest fuel cell operating point (11.2 kBtuh at the 2.5 kW set point). Figure 5 shows the average load to be about 1 kBtuh with a diurnal cycle that exhibits morning and evening peaks of 2 to 5 kBtuh. The average electric production efficiency (LHV basis including all parasitic loads) in July 2004 was 28.5% and the CHP efficiency was 43%.

In the case of the CGS, thermal loads are substantial but still have a diurnal variation, as shown for July 2004 in Figure 6. Figure 6 illustrates a base load of about 8 kBtuh, which is well matched to the 11 kBtuh available with a fuel cell operating point of 2.5 $kW_e$. The diurnal fluctuations in thermal load are small—typically less than 2 kBtuh. In short, this is an ideal thermal load for this DG/CHP application. The dropouts on July 27 to 29, 2004, represent fuel cell downtime rather than the absence of thermal load. Electric and CHP efficiency cannot be calculated for CGS

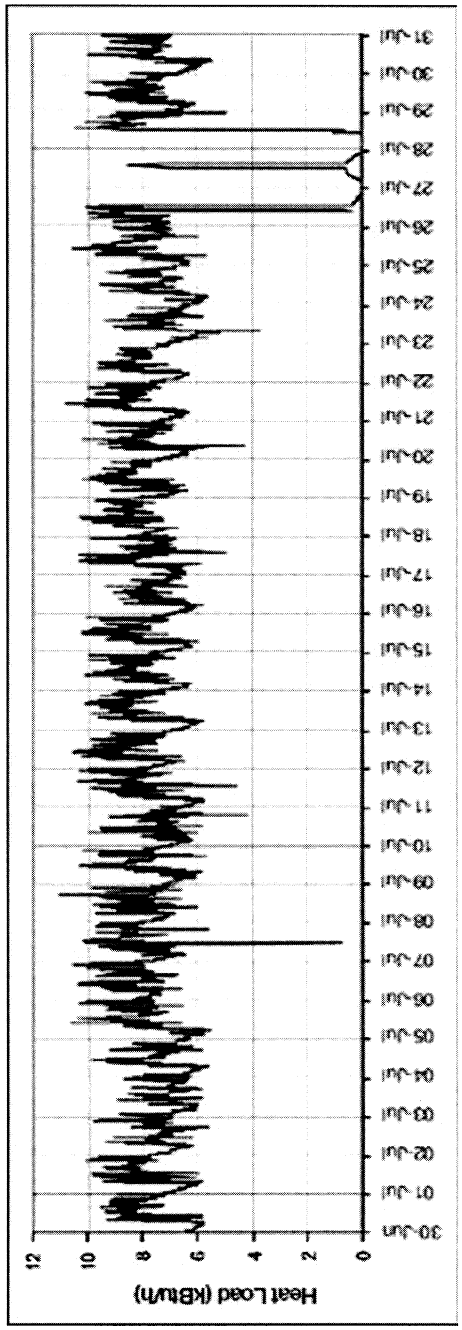


**Figure 6. Heat Output by the Coast Guard Station Demonstration Unit, July 2005.**

because the electric meter is reading only the emergency panel portion of electricity production.

## FUTURE DEVELOPMENTS

Package DG/CHP fuel cell technology is evolving rapidly. In addition to understanding the current state of the technology, a potential user should consider technology advances that may be in the pipeline. A few possibilities, some of which are slated to appear by the $4^{th}$ quarter of 2005, are outlined below.

### Control

In many cases, it makes sense to configure the plant either to satisfy a dedicated load (load tracking) or to maintain a constant output of power, part of which may feed a critical load while the balance sold to the grid. However, in other cases, there can be significant benefits to a more sophisticated control strategy. Such cases may involve control based on time of use rates, real-time rates, or response to a utility curtailment program. In some cases, optimal or mission-critical operation may require load tracking of the thermal load or real-time switching between electrical and thermal load tracking.

### Site Approval

The demonstration unit satisfies California Air Resource Board (CARB) standards for small, low-emission DG and DG/CHP plants, as indicated in Appendix C. However, until installations become commonplace and familiar to building inspectors and other regulators, the site approval process is likely to present challenges for some sites. Some possible issues are water supply, hot waste water, utility interface, and emergency access (paved driveway).

### High Water Use

The next-generation package is expected to have zero net water use. This would eliminate much of the expected maintenance as well as some of the potential site approval hurdles involving backflow prevention and hot water emissions. With balanced water management, hot water emission would be approximately halved and cold water emission would be zero.

**High Cost**

Product cost is certainly one of the important drivers but second to maintenance. Currently, there is enough of a market in remote and critical power to justify the high cost, low volume production. This can be expected to gradually improve as competition and market volume increase.

**Maintenance Burden**

Package designs are evolving steadily based on manufacturing and field experience. The two main maintenance costs are cell stack replacement and water supply (improved design and reliability).

**On-line Data**

The demonstration unit has an embedded data acquisition system used by the manufacturer to gain valuable performance and diagnostic data. However, key M&V data are not collected. It would be more attractive to many end-users if internal meters for cumulative gas input, inverter output, and heat recovery output were offered as factory options than to have this equipment installed externally on-site, as is current practice. The power meter option is a particular need because one meter between the inverter output and internal transfer switch can handle both the main and emergency panel loads; two meters, or a meter that can accommodate the two load feeds (e.g., through the eye of a current transformer) are required to properly measure the power externally.

## BENEFITS

Fuel cells have been shown to be capable of unattended operation in combined heat and critical power applications selected for the DOD fuel cell demonstration program. Although it has not been explicitly demonstrated in the program, the technical potential for DG to serve as a peak-shaving resource certainly exists. What has been demonstrated is the ability for fuel-cell based DG to provide "hot" back-up for mission- essential loads in commercial and residential applications. CHP addresses the common wasteful practice of producing of low-grade heat by direct burning of fossil fuel. Currently, the reliability and availability statistics are in need of improvement. In the long term, fuel cell technology could become one of the cornerstones of distributed generation, wherein low-energy buildings approach zero net electricity use by producing most of their own power needs from photovoltaic collectors, natural gas, or hydrogen.

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**Additional Sources of Information**

Binder MJ, WR Taylor and FH Holcomb. 2001. Experience with the DOD fleet of 30 fuel cell generators, 2001 Int'l Gas Research Conf., Amsterdam Nov 5-8, 2001.

Connected Energy Corporation, Internet site for monitoring Logan Energy U.S. Fuel Cell Sites, https://enerview.com/EnerView/login.asp (log in with user name "logan.user" and password "guest")

DOD Fuel Cell ERDC/CERL Projects. Internet site for the DOD fuel cell demonstration program. www.dodfuelcell.com

Fuel Cells 2000. www.fuelcells.org

Hadley, S.W., et al. 2002. Analysis of CHP Potential at Federal Sites. ORNL/TM-2001/280. Oak Ridge National Laboratory, Oak Ridge, TN. www.ornl.gov/sci/femp/pdfs/chp_market_analysis.pdf

LoganEnergy. 2003. Initial Report FY '01 CERL PEM Demonstration Program: Ft. McPherson PEM Project, Atlanta, GA. December 31, 2003. http://dodfuelcell.cecer.army.mil/res/InitialReport_FtMcPherson.pdf.

LoganEnergy, 2003. Initial Report FY '01 CERL PEM Demonstration Program: U.S. Coast Guard Station PEM Project, New Orleans, LA. January 3, 2003. http://dodfuelcell.cecer.army.mil/res/Initial-Report_CoastGuardNO.pdf

National Fuel Cell Research Center. www.nfcrc.uci.edu/educational_index.htm

Plug Power. 2004. Proposal for Natural Gas PEM Fuel Cell Demonstration, Generic Proposal (60 Hertz NG). Unpublished but available from Plug Power, Latham, NY.

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ABOUT THE AUTHORS

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**Greg Sullivan, P.E., C.E.M**., is a Senior Research Engineer at the Pacific Northwest National Laboratory where he has worked for the past 12 years. His research interests include resource efficiency, end-use metering, and technology evaluation. He holds his B.S. in Physics from the University of Oregon, B.S. in Mechanical Engineering from Oregon State University, and M.S. in Building Engineering from MIT. Greg is a registered Professional Engineer in the state of Washington and a Certified Energy Manager. Greg may be contacted at gp.sullivan@pnl.gov.

## APPENDIX A—SPECIFICATIONS

Manufacture's specifications for the DG/CHP fuel cell package demonstrated at Fort McPherson.

| **Specifications** | | |
|---|---|---|
| Physical Size | L x W x H | 84 1/2" X 32" X 681/4" |
| Performance | Power Rating | 5 kW continuous |
| | Power Set Points | 2.5 kW, 4 kW, 5 kW |
| | Voltage | 120/240 VAC @ 60 Hz |
| | Power Quality | IEEE 519 |
| | Emissions | $NO_X$ < 5 ppm |
| | | $SO_X$<1 ppm |
| | Noise | < 70 dBa @ 1meter |
| Operating Conditions | Temperature | 0°F to 104°F |
| | Elevation | 0 to 750 feet |
| | Installation | Outdoor/CHP |
| | Electrical Connection | GC/GI |
| | Fuel | Natural Gas |
| Certifications | Power Generation | CSA International |
| | Power Conditioning | UL |
| | Electromagnetic Compliance | FCC Class B |
| Dimensions | | |
| Length | | 84 inches |
| Width | | 32 inches |
| Height | | 68-1/4 inches |
| Operating Requirements | | |
| Fuel Type | | Natural Gas |
| Temperature | | 0°F to 104°F |
| Outputs | | |
| Power Output | | 5 kW |
| Voltage | | 120/240 VAC @ 60Hz |
| Noise | | < 70 dBA@ 1 meter |
| Certifications | | |
| CSA International | | Fuel Cell System |
| UL | | Power Conditioning Module |

## APPENDIX B—LIFE-CYCLE COST ANALYSIS

Initial life-cycle cost estimates for the Fort McPherson PEM fuel cell demonstration are contained in the Initial Project Description Report available on the DOD Fuel Cell web site at http://dodfuelcell.cecer.army.mil/res/InitialReport_FtMcPherson.pdf. More up-to-date performance information is available at http://dodfuelcell.cecer.army.mil/res/site_summary_statistics.php4?site_id=15.

Assuming the fuel cell operates at an average 2.5 kW capacity with an average availability of 90%, the following life-cycle cost analysis results from using BLCC version 5.1.

**NIST BLCC 5.1-02: Comparative Analysis**
Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

**Base Case**: Baseline
**Alternative**: PEM Fuel Cell

**General Information**

| | |
|---|---|
| File Name: | C:\My Documents\McPherson Fuel Cell Analysis.xml |
| Date of Study: | 2004 |
| Project Name: | Fort McPherson Fuel Cell Assessment |
| Project Location: | Georgia |
| Analysis Type: | MILCON Analysis, Energy Project |
| Analyst: | J. Doe |
| Base Date: | April 1, 2004 |
| Beneficial Occupancy Date: | April 1, 2004 |
| Study Period: | 10 years 0 months (April 1, 2004 through March 31, 2014) |
| Discount Rate: | 3.2% |
| Discounting Convention: | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| **Initial Investment Costs:** | **Base Case** | **Alternative** | **Difference** |
|---|---|---|---|
| Capital Requirements as of Base Date | $0 | $83,825 | -$83,825 |
| **Future Costs:** | | | |
| Energy Consumption Costs | $13,663 | $11,737 | $1,926 |
| Energy Demand Charges | $0 | $0 | $0 |
| Energy Utility Rebates | $0 | $0 | $0 |
| Water Costs | $0 | $71 | -$71 |
| Routine Recurring and Non-Recurring OM&R Costs | $0 | $128,672 | -$128,672 |
| Major Repair and Replacements | $0 | $0 | $0 |
| Residual Value at End of Study Period | $0 | $0 | $0 |
| Subtotal (for Future Cost Items) | $13,663 | $140,480 | -$126,817 |
| **Total PV Life-Cycle Cost** | $13,663 | $224,305 | -$210,642 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| PV of Non-Investment Savings | -$126,817 |
| —Increased Total Investment | $83,825 |
| **Net Savings** | -$210,642 |

Note: Meaningful SIR, AIRR and Payback can not be computed unless incremental savings and total savings are both positive.

### Energy Savings Summary

**Energy Savings Summary (in stated units)**

| Energy Type | -------- Average Annual Consumption --------- Base Case | Alternative | Savings | Life-Cycle Savings |
|---|---|---|---|---|
| Electricity | 19,710.0 kWh | 0.0 kWh | 19,710.0 kWh | 197,019.1 kWh |
| Natural Gas | 62.0 MBtu | 258.9 MBtu | -196.9 MBtu | -1,967.8 MBtu |

**Energy Savings Summary (in MBtu)**

| Energy Type | -------- Average Annual Consumption --------- Base Case | Alternative | Savings | Life-Cycle Savings |
|---|---|---|---|---|
| Electricity | 67.3 MBtu | 0.0 MBtu | 67.3 MBtu | 672.3 MBtu |
| Natural Gas | 62.0 MBtu | 258.9 MBtu | -196.9 MBtu | -1,967.8 MBtu |

## APPENDIX C—CALIFORNIA AIR RESOURCE BOARD CERTIFIED TECHNOLOGIES

Once an Executive Order of DG Certification is issued to a manufacturer, it is posted on the CARB website: http://www.arb. ca.gov/energy/dg/dg.htm. Below are Executive Orders for DG Certification issued as of January 2005.

| Company Name | Technology | Standard Order | Executive Date | Expiration |
|---|---|---|---|---|
| United Technologies Corporation | Fuel Cells 200 M, Phosphoric Acid Fuel Cell | 2007 | DG-001 | 29-Jan-07 |
| CapstoneTurbine Corporation | 60 M, C60 MicroTurbine | 2003 | DG-002 | 31 -Dec-06 |
| FuelCell Energy, Inc. | FuelCell Energy, Inc. 250 M DFC300A | 2007 | DG-003 | 7-May-07 |
| Ingersoll-Rand Energy Systems | 70 M, 70LM Microturbine, version C | 2003 | DG-004-A | 31-Dec-06 |
| Ingersoll-Rand Energy Systems | 70 kW1 70LM Microturbine, version WD (CHP) | 2003 | DG-005 | 31-Dec-06 |
| Plug Power Inc. | 5 M, GenSys™ 5C Fuel Cell | 2007 | DG-006 | 16-Jul-08 |
| FuelCell Energy, Inc. | 1 MW, DFC 1500 Fuel Cell | 2007 | DG-007 | 13-Sep-08 |