Federal Technology Alert

A publication series designed to speed the adoption of energy-efficient and renewable technologies in the Federal sector

Prepared by the New Technology Demonstration Program

DoD EPA DOE SERDP
Strategic Environmental Research and Development Program
Improving Mission Readiness through Environmental Research

Natural Gas Fuel Cells

Technology for improving energy efficiency while reducing environmental emissions

A natural gas fuel cell (NGFC) is a simple, reliable way to improve natural gas utilization and efficiency. This technology converts natural gas into electricity to provide a quiet, clean, and highly efficient on-site electric generating system and thermal energy source that can reduce facility energy service costs by 20% to 40% over conventional energy service.

This *Federal Technology Alert* (FTA), one of a series on new technologies, describes the theory of operation, energy-saving mechanisms, range of applications, and field experience for the NGFC technology.

Energy-Saving Mechanism

The NGFC is a simple, reliable direct conversion system. A fuel cell is an electrochemical system rather than a combustion system. Its operation is closely akin to that of a battery system, except that it consumes fuel. The energy savings results from the high conversion efficiency, typically 40% or higher, depending on the type of fuel cell. When utilized in a cogeneration application by recovering the available thermal energy output, overall energy utilization efficiencies can be on the order of 85% or more.

The figure below shows the primary subsystems of an NGFC. An additional thermal management subsystem (not shown) may be required if cogeneration thermal energy is not fully utilized. There are several types of NGFC, all having the following general characteristics:

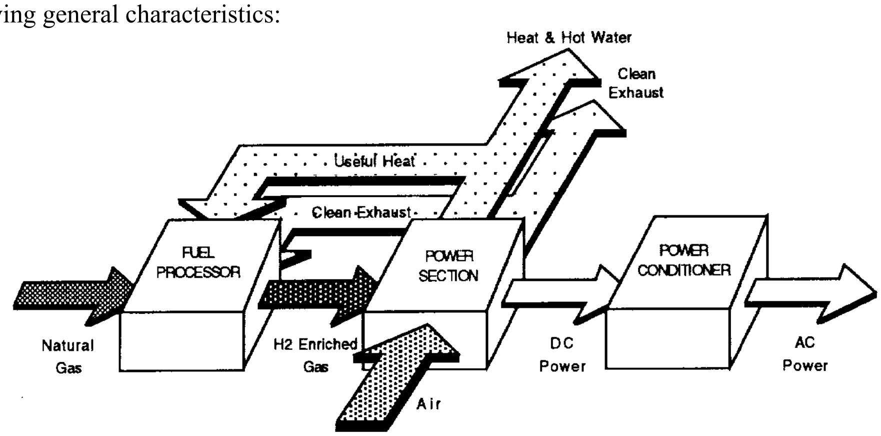
- They can be sized to accommodate different capacity needs by "stacking" the same cell designs.
- Their high conversion efficiency is relatively independent of system capacity.
- They are environmentally benign because of their low emissions.

At present, however, only one type of NGFC system is commercially available in the United States, the phosphoric-acid-based fuel cell. The phosphoric acid operates as the electrolyte in the power section. Three other electrolytes are still being testing in other fuel cell designs: molten carbonate, solid oxide, and polymer electrolytes.

Technology Selection

The NGFC is just one of many energy technologies to emerge in the last 20 years. The FTA series targets technologies that appear to have significant Federal-sector potential and for which some Federal installation experience exists. These FTAs seek to identify if product claims are true or are simply sales hype.

New technologies were identified through advertisements in the *Commerce Business Daily* and trade journals, and through direct correspondence. Numerous responses were obtained from manufacturers, utilities, trade associations, research institutes, Federal sites, and other interested parties.



Technologies suggested were evaluated in terms of potential energy, cost, and environmental benefits to the Federal sector. They were also categorized as those that are just coming to market and those for which field data already exist. Technologies classified as just coming to market are considered for field demonstration through the U.S. Department of Energy's Federal Energy Management Program (FEMP) and industry partnerships. Technologies for which some field data already exist are considered as topics for FTAs. The NGFC technology was found to have significant potential for Federal-sector savings and to have demonstrated energy-saving field experience.

Potential Benefits

Besides the possible cost savings available with NGFC, there are environmental benefits associated with installing this technology. Because NGFCs convert fuel to electricity through an electrochemical process rather than a combustion process, the emissions are much cleaner, primarily carbon dioxide and water. The low emission levels have attracted the attention of many air quality management districts around the country, and some districts have granted NGFCs blanket exemption from air quality permitting. This exemption could become a major factor in the decision to install and operate an NGFC, especially in areas where new permits are not being issued or in instances where operational emissions levels are being exceeded.

Application

On the basis of FEMP analysis and review of evaluations by others, the NGFC technology is recommended for deployment at Federal facilities when it can be applied in a cogeneration configuration as a base load electric and thermal supply system. The following conditions favor use of an NGFC system:

- Where natural gas costs are low and electricity and demand costs are high
- Where the thermal energy can be recovered and utilized (the NGFC can become more cost effective operating as a cogeneration system)
- Where compliance with stringent environmental air quality regulations is limiting the options available to meet electric power requirements
- Where critical electric loads are currently being supplied by high-cost uninterruptible power supplies, motor-generator sets, or back-up generators running on fossil fuels
- Where computers, telecommunications equipment, electronic security systems, or other electronic control systems demand a noise-free, highly reliable, high-quality electric energy source.

An NGFC system is least cost-effective under the following conditions:

- In a cogeneration configuration for use in either a thermal-load-following or electric-load-following control strategy. In these strategies, the fuel cell operates at some part-load factor. Depending on the relative natural gas and electric costs, full-load operation (base loading) typically offers the best life-cycle-cost economics.
- In systems using sophisticated thermal recovery and control systems that are designed to recover the maximum available thermal energy. In these systems, the cost of the thermal energy recovery equipment may outweigh the potential economic benefit.

Field Experience

NGFC installations have been monitored in many commercial sites and a few Federal sites by utility engineers and site facility managers. Feedback from owners/operators has been extremely positive. System electric conversion efficiencies of 40% and availabilities of 97% or more are being reported on the latest models installed. The experience gained and the lessons learned from the commercial NGFC systems installed to date have conclusively validated the phosphoric-acid fuel cell (PAFC) technology.

The only negative feedback received dealt with initial installation, permitting, and/or electric grid interconnection issues rather than actual system operation or performance. During the installation of over 20 units throughout the country, only two permitting issues were raised and those have already been addressed by the PAFC manufacturer.

Owners and operators have joined to form an independent users group, the North American Fuel Cell Owners Group (NAFCOG), to share information on applications, siting, installation operation and maintenance experiences. The reader is strongly encouraged to contact the members of this group. Contact names and phone numbers are listed in the FTA section "Who is Using the Technology."

Case Study

A hypothetical case study from a Federal facility in southern California was developed to illustrate the process for determining the cost effectiveness of a 200-kW phosphoric-acid-based NGFC. The analysis uses the San Diego Gas and Electric (SDG&E) general service-large-time metered secondary electric rate schedule (AL-TOU) and the GPTCI natural gas rate schedule for the local cost of energy.

Assuming the fuel cell is operated continuously at full load and that 75% of the available thermal energy can be recovered and used to offset the load of an existing boiler system operating at 80% efficiency, the fuel cell energy consumption is determined and evaluated against the value of the avoided electricity costs and the value of the avoided boiler fuel consumption. Annual maintenance costs for operating the fuel cell are estimated at $26,000/yr. The estimated cost of the NGFC is $600,000 with an additional $50,000 for installation. However, with the Federal cost sharing program, the net cost to the site is estimated to be $450,000. The life of the NGFC is estimated to be 20 years. Life-cycle costs were determined using the NIST Building Life-Cycle Cost (BLCC) program. The total life-cycle cost for the NGFC alternative was calculated to be $1,908,000, compared with conventional energy service with a life-cycle cost of $2,007,000, for a net-present value of over $99,000. The savings-to-investment ratio (SIR) for installing the NGFC was 1.22.

This case study is only an example. The actual implementation of NGFC technology is unique to each site. Readers interested in a specific application are encouraged to contact the NAFCOG or the NGFC manufacturer's representative to identify an owner/operator with a similar application or installation.

Implementation Barriers

The future of natural gas fuel cells in the Federal sector looks good. There are many potential applications for fuel cells, including prime power supply, interruptible power supply, and cogeneration supply. Because of the potential for reducing site emissions, improving power quality, and increasing power reliability, as well as the life-cycle cost economics, the market for natural gas fuel cells is anticipated to grow.

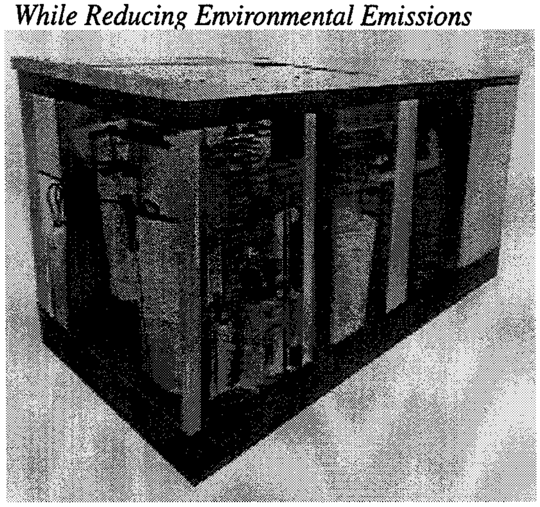
The only remaining barriers to implementation involve gaining user acceptance of this alternative energy production technology and reducing the initial cost of the NGFC.

Federal energy managers and technology program managers who are familiar with NGFC systems are listed in this FTA. The reader is invited to ask questions and learn more about the NGFC technology.

Federal Technology Alert

Natural Gas Fuel Cells

Technology for Improving Energy Efficiency While Reducing Environmental Emissions



Abstract

The natural gas fuel cell (NGFC) energy system is a simple, reliable way to improve natural gas utilization and efficiency. This technology converts natural gas into electricity to provide a quiet, clean, and highly efficient on-site electric generating system and thermal energy source that can reduce facility energy service costs by 20% to 40% over conventional energy service. The NGFC utilizes an alternative cogeneration technology for improving natural gas utilization and efficiency. It is an environmentally friendly fossil-fueled energy generator with cleaner emissions than the ambient air in some cities. NGFCs can serve effectively as an on-site energy supply to meet needs for base-load electricity, heat, and hot water, while local electric and natural gas utilities provide for energy demand beyond the NGFC capacity.

This *Federal Technology Alert* (FTA) contains detailed information and procedures that a Federal energy manager can use to evaluate most NGFC applications. The New Technology Demonstration Program (NTDP) technology-selection process and general benefits to the Federal sector are outlined. Principles of NGFC operation and their energy-saving mechanisms are explained. Procedures are given for preliminary sizing of equipment, estimating energy savings, and calculating life-cycle costs (LCC). Proper application, installation, and operations and maintenance (O&M) impacts are discussed. A hypothetical Federal-sector case study is presented to assist the reader in estimating energy consumption and costs associated with NGFC installation and operation. A list of Federal-sector users and a bibliography are included for prospective users who have specific or highly technical questions not fully addressed in the FTA. Details of life-cycle cost analysis and an example procurement specification are also provided as appendixes.

Contents

About the Technology

A natural gas fuel cell (NGFC) is a direct-energy conversion system with no moving parts. Like batteries, fuel cells are based on the principles of electrochemistry, except that they consume fuel to maintain the chemical reaction. The most common electrochemical reaction in a fuel cell is that of hydrogen with oxygen. The oxygen is usually derived from the air, and the hydrogen is usually obtained by steam-reforming fossil fuel. Natural gas is the most commonly used fuel; however, other fuels can be used: peak-shaved gas, air-stabilized gas from local production such as landfills, propane, or other fuels with high methane content. Fuel cells, being electrochemical devices, are more efficient than Carnot cycle heat engines used in combustion systems. Typical fuel cell fuel-to-electricity conversion efficiencies range from 40% to 60%. A typical fuel cell installation is shown in Figure 1. This installation is at the Pittsburgh International Airport, where the fuel cell is used to provide 200 kW of continuous power and the recoverable thermal energy is used for space heating U.S. Air's hanger #2 (Randazzo 1993).

NGFC technology can be a net-energy-saving technology when viewed from a source energy perspective. The high conversion efficiency of a fuel cell reduces total fuel consumption when the prime energy source for electric generation is taken into account. At an individual site's boundary, however, total energy crossing the boundary will increase because fuel cells consume natural gas to generate electricity and are less than 100% efficient.

NGFC technology is an energy-cost-reduction technology. For sites with low natural gas costs and high electricity or electrical demand costs, NGFC can be a cost-effective energy technology alternative. The cost savings comes from fuel switching. By reducing electricity consumption and increasing natural gas consumption, operational energy costs can be reduced by 25% to 40% over conventional energy service.

Application Domain

Approximately 250 phosphoric acid fuel cell (PAFC) units, 35 molten carbonate fuel cell (MCFC) units, and 12 solid oxide fuel cell (SOFC) units have been or are operating in as many as 16 countries around the world, with a total capacity of around 45 MW (Hirschenhofer 1994). Although many fuel cells are being researched, developed, and demonstrated around the world, currently there is only one system commercially available in the United States. It is a 200-kW PAFC system manufactured by ONSI Corporation, a subsidiary of International Fuel Cells, Inc. The PC25™ Model C is the company's current production model. As of the end of 1994, 69 of ONSI's commercial PC25™ A and B models had been delivered and had begun service. By March 1995, 4 of these units had achieved 20,000 hours of operation, with the longest continuous operation of a system being 7,570 hours, or 10-1/2 months. The

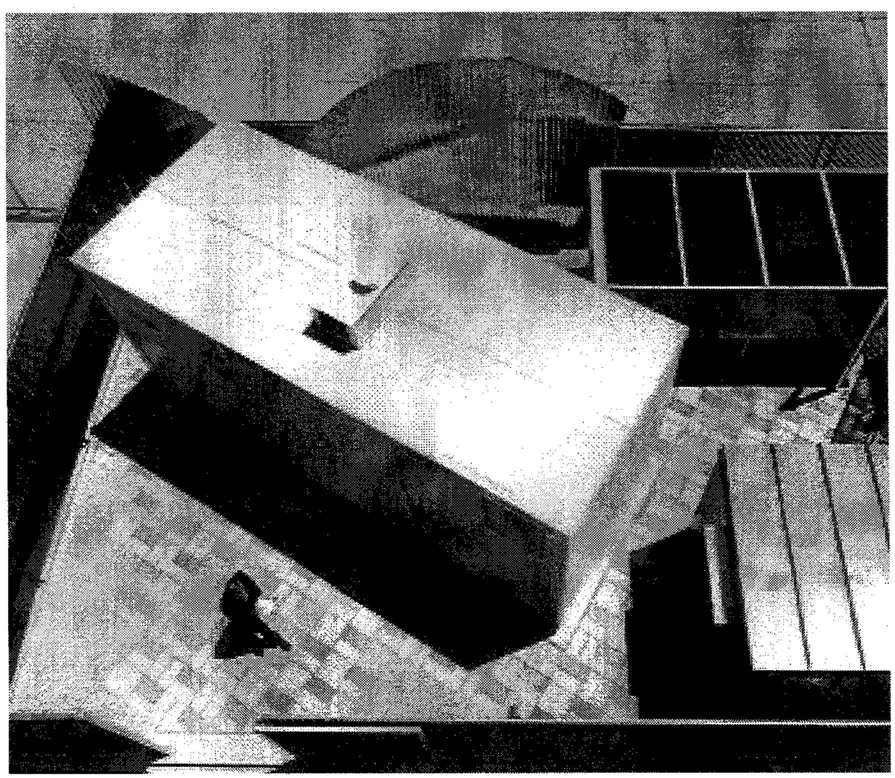


Fig. 1. An NGFC System Installed at the Pittsburgh International Airport

entire commercial fleet had accumulated over 600,000 hours of operation, with an average availability factor of 95% and an electric conversion efficiency of 40%[(a)] (Hirschenhofer 1995). By September 1995, the manufacturer reported that 12 of the units had achieved 20,000 hours of operation with the longest continuous operation being 8,760 hours. In addition, the entire commercial fleet had accumulated over 700,000 hours of operation.

The possible installation options available with an NGFC vary widely, depending on how the electricity is being used and if any thermal energy is being recovered. A schematic representation of a conventional energy supply system and the options available by incorporating a fuel cell is presented in Figure 2. With the conventional system identified as option a), the three primary alternative options shown in the figure are b) a prime power supply, c) an interruptible power supply, and d) a cogeneration system. The cogeneration system incorporates both electric power supply and the recovery of thermal energy. Options b and c are site- and user-specific alternatives. Their selection may be subject to a number of drivers that may override energy-efficiency objectives.

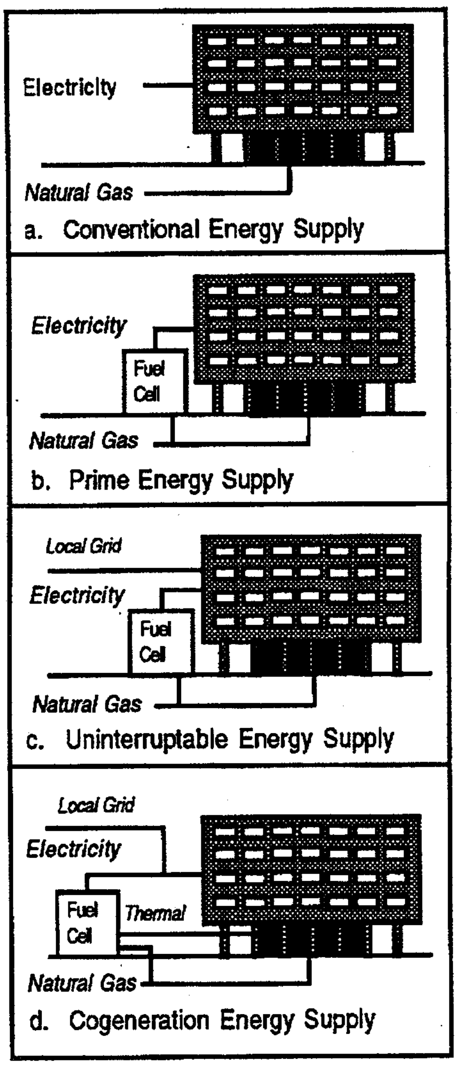


Fig. 2. NGFC Application Options

Of the 69 commercial NGFCs installed worldwide, 24 are located in the United States. Of these installations, all but two are utilized as cogeneration systems (Figure 2, option d), where the waste heat from the fuel cell unit is used to heat space, domestic water, service water, laundry water, industrial processes, or for other heating requirements (McClelland 1994).

Energy-Saving Mechanism

The fuel cell is very much like a battery; it contains electrodes (anodes and cathodes) separated by an electrolyte. But unlike a battery, a fuel cell consumes fuel and does not require recharging. Also, fuel cells are exothermic, producing heat as a byproduct of the chemical reaction, and this heat is available for cogeneration applications.

Fuel cell systems are categorized by the type of electrolyte. Four major categories are currently being employed: phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC), and polymer electrolyte fuel cells (PEFC). The basic fuel cell characteristics are presented in Table 1 (Hirschenhofer 1995). The physicochemical and thermomechanical properties of the materials used in a fuel cell, especially the electrolyte, determine the practical operating temperature and useful lifetime of the operational fuel cell. Solid polymer and aqueous electrolytes are limited to temperatures of 200°C or less to avoid high water-vapor pressure and/or rapid degradation of the electrolyte. The operating temperature of MCFCs is determined by the melting point of the electrolyte, and the operating temperature of SOFCs is determined by the ionic conductivity of the electrolyte. The lower-temperature fuel cells, PEFC and PAFC, utilize aqueous electrolytes and are mostly restricted to using hydrogen as the reactant. The presence of carbon monoxide and sulfur-containing gases in the fuel stream serves to poison the anode and thus to degrade cell performance. In high-temperature fuel cells, SOFCs and MCFCs, a wider variety of fuels can be used because electrode kinetics are more rapid and the higher operating temperature reduces the need for high electrocatalytic activity. Also in these cells, because of the higher operating temperature, fuel reforming may be done internally to the cell or other hydrocarbon fuels could be chosen that could be used directly. In low-temperature fuel cells, the primary charge carriers are either protons or hydroxyl ions, whereas carbonate and oxide ions are the primary charge carriers in high-temperature fuel cells.

In addition to their group characteristics, fuel cells have the following general traits:

- They can be sized to accommodate different capacity needs by connecting the same cell designs in series and/or parallel, referred to as "stacking" cells

(a) Based on the lower-heating value (LHV) of the fuel, 36% based on the higher-heating value (HHV).

- Their high conversion efficiency is relatively independent of system capacity

- They are environmentally benign because of their low emissions.

An NGFC system is composed of three primary subsystems: a fuel processor or reformer, a fuel cell stack, and a DC-to-AC power converter. These subsystems are illustrated in Figure 3. A secondary subsystem for thermal management (a cooling module) is required if recoverable thermal energy is not fully utilized in some form of cogeneration application. The fuel processor combines natural gas with steam (recovered from the power section) to reform the fuel into a hydrogen-rich mixture for use by the fuel cell stack in the power section. In the power section, the fuel mixture, rich in hydrogen, is combined with oxygen from the air to produce DC electricity. The process generates heat and produces carbon dioxide and water as exhaust gases. The DC-to-AC power converter takes the DC electricity from the fuel stack and converts it to usable AC power such as 480-volt, 60-cycle, 3-phase AC.

There is currently only one commercially available NGFC system in the United States. It is a phosphoric-acid-based cell manufactured by ONSI, a subsidiary of International Fuel Cells. ONSI produces a 200-kW PAFC unit with the ability to provide up to 700,000 Btu/hr (205 kW)[a] of thermal energy or at temperatures up to 165°F (73.9°C). The unit has a rated output of 200 kW/235 kVA with a fuel consumption rate of 1,900 scfm natural gas rated at a HHV of 1,000 Btu/ft^3 (1.9 million Btu/hr [556.9 kW]).

Table 1. Fuel Cell Characteristics

Cell Type	Potential Applications	Output (MWe)	Date Available	Efficiency (Elect./Cogen.)	Temp.
PAFC	Dispersed Electric On-Site Cogeneration	1 to 10 0.2 to 1	1996 1992	41% 40% (80%)	200°C
MCFC	Dispersed Electric On-Site Cogeneration Central Power	1 to 10 0.25 to 1 100 and above	1997+ 1997+ 2000+	50 to 55% 45% (70%) 50 to 60%	650°C
PEFC	On-Site Electric	0.25	2000+	40+%	80°C
SOFC	Dispersed Electric Central Power	1 to 10 50 and above	2000+ 2000+	50+% 50+%	1,000°C

Other Benefits

Besides the possible cost savings available with NGFC, there are environmental benefits associated with installing this technology. Because NGFCs convert the fuel to electricity through an electrochemical process rather than a combustion process, the emissions from the NGFC are much cleaner and are primarily carbon dioxide and water. The low emissions level of the NGFC has attracted the attention of many air quality management districts around the country. Some districts have granted NGFCs blanket exemption from air quality (emission) permit requirements. This exemption could become an overriding factor in the decision to install and operate an NGFC, especially in areas where new emission permits are not being issued or in instances where operational emission levels are being exceeded.

Variations

Information on the commercially available PAFC NGFC identifies a few options that expand the capability and potential applications of the system. These options include alternative utility-grid connection capabilities, double-wall heat exchangers, high-grade heat recovery, propane gas, peak-shave gas, a gas-fired heater, and a remote data acquisition and control system.

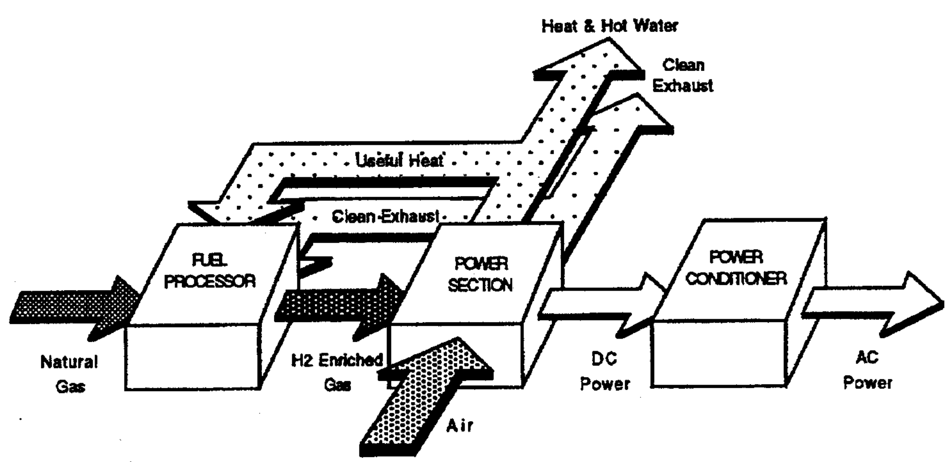


Fig. 3. Schematic of an NGFC System

(a) Actual heat recovery rate is dependent on system load, flow rate, hot water supply and return temperatures, see ONSI (1995b).

Alternative grid connections. There are three options for the fuel cell electric system to operate relative to the utility electric grid. The plant can operate as a power plant with the dual capability of grid-independent and grid-connected, single grid-independent/grid-synchronized, or multiple units operating in parallel independent from the grid.

- Grid-Independent/Grid-Connected: In this configuration, the fuel cell normally is connected to the utility grid. If utility power is lost, the fuel cell will automatically disconnect from the utility grid and switch to a grid-independent mode, thus operating as an emergency generator. The fuel cell power output will load and unload in response to the demand on the system.

- Grid-Independent/Grid-Synchronized: In this configuration, the fuel cell operates in synchronization with the utility grid, but primary power comes from the fuel cell. A static switch is used to transfer the loads to the electric utility grid whenever the fuel cell goes off-line.

- Parallel Operation of Multiple Grid Independent Units: This configuration allows two or more fuel cells to operate in parallel with each other independent of the grid.

Double-wall heat exchanger. The fuel cell typically uses a propylene glycol-water loop in the thermal recovery system. For domestic hot water applications, many local codes require a double-wall heat exchanger to prevent the possibility of cross-contamination between the glycol solution and the potable water in the event of a leak in the heat exchanger wall.

High-grade heat recovery. In the standard configuration, waste heat can be recovered up to around 600,000 Btu/h (176 kW) at temperatures up to 165°F (74°C). In this alternative configuration, the fuel cell can provide more than 350,000 Btu/h (102.6 kW) at temperatures up to 250°F (121°C). The remaining thermal energy can still be recovered at around 140°F (60°C).

Propane. This *Technology Alert* has concentrated on natural gas fuel cells; however, many Federal sites have access to propane but not to natural gas. Propane as a primary fuel is an available option.

Peak-shave gas capability. Some natural gas utilities use peak-shave gas during periods of high demand. Natural gas fuel cells can be configured to operate using peak-shave gas. There are, however, some limitations; readers are encouraged to discuss this option with their natural gas utility and the fuel cell representative.

Gas-fired heater. Natural gas fuel cells utilize electric heaters during the startup process. If the system is connected to the electric utility grid, this is generally not a concern. If the system is operated independent from an electric grid, an optional gas-fired heater may be used.

Remote data acquisition and control. This option allows transmission of data from the fuel cell control system to a remote computer terminal through a modem and telephone lines. This option allows for the collection of operational data as well as complete remote control of the fuel cell, including startup, shutdown, and diagnostics.

Installation

The NGFC system is designed for indoor or outdoor installation, including roof tops. Ground-level outdoor installation is generally preferred, on concrete pads located as close as possible to the thermal and electrical interfaces. At present the NGFC manufactured by ONSI consists of two modules: a power module 10x18x10 feet (3.0x5.5x3.0 meters) weighing 40,000 pounds (18,144 kg) and a cooling module 4x14x4 feet (1.2x4.3x1.2 meters) weighing 1,500 pounds (680 kg). For indoor or roof top installations, a minimum load-bearing capacity of 250 lb/ft^2 (97.6 kg/m^2) is needed for the power module and 30 lb/ft^2 (146.5 kg/m^2) is needed for the cooling module. Indoor installations require additional inlet and outlet air ducting and fans to provide for system cooling by ventilation.

The manufacturer recommends a minimum 8-foot (2.4 m) clearance around the power module for maintenance activities. It is recommended that the cooling module be installed around 8 feet (2.4 m) away from the power module to minimize the footprint requirements and connection costs for piping and wiring; however, the cooling module may be installed up to 100 feet (30.5 m) from the power module.

NGFC users have indicated that installation costs range between \$50,000 and \$80,000, for a typical outdoor ground level installation on concrete pads, and up to or exceeding \$100,000 for more complicated designs and landscaped installations. Installation costs also escalate with the complexity of the thermal energy recovery system design. For most cogeneration applications, the heat recovery system is generally designed to recover an average 75% of the available thermal energy. The costs of designing more elaborate heat recovery and control systems in order to recover all of the available thermal energy can exceed acceptable savings-to-investment ratios, although this is generally a site-specific issue.

Federal Sector Potential

The potential cost savings achievable by NGFC technology were estimated as a part of the technology assessment process of the New Technology Demonstration Program (NTDP). The overall life-cycle cost-effectiveness is significantly affected by the initial capital cost of the system. Present costs are $3,000/kW, but the goal is for the cost to drop to $1,500/kW within the next 5 years.

Technology Screening Process

New technologies were solicited for NTDP participation through advertisements in the *Commerce Business Daily*, trade journals, and through direct correspondence. Numerous responses were obtained from manufacturers, utilities, trade associations, research institutes, Federal sites, and other interested parties. Based on those responses, the technologies were evaluated in terms of potential Federal-sector energy savings and procurement, installation, and maintenance costs. They were also categorized as either just coming to market ("unproven" technologies) or as technologies for which field data already exist ("proven" technologies). [Note: This solicitation process is ongoing and as additional suggestions are received, they are evaluated and become potential NTDP participants.] The energy savings and market potentials of each candidate technology were assessed using a modified version of the Facility Energy Decision Screening (FEDS) software tool, developed for the Federal Energy Management Program (FEMP), the Construction Engineering Research Laboratories (CERL), and the Naval Facilities Engineering Service Center (NFESC), by the Pacific Northwest Laboratory (PNL) (Dirks and Wrench 1993).

Estimated Savings and Market Potential

During the solicitation period in which NGFCs were suggested, 21 of 54 new energy-saving technologies were assessed using the modified FEDS. Thirty-three were eliminated in the qualitative pre-screening process for various reasons: not ready for production, not truly energy-saving, not applicable to a sufficient fraction of existing facilities, or not a U.S. technology. Eighteen of the remaining 21 technologies, including NGFCs, were judged life-cycle cost-effective (at one or more Federal sites) in terms of installation cost, net present value, and energy savings. In addition, significant environmental savings from many of these technologies are likely through reductions in CO_2, NO_x, and SO_x emissions. Several of these technologies that have demonstrated field performance have been slated for further study through *Federal Technology Alerts*.

The 18 technologies have an estimated aggregate first cost of $884 million, a net present value (NPV) of $1,055 million, aggregate site energy-saving potential of 8,934 trillion Joule/yr (8,468 billion Btu/yr), and a present value of energy and operations and maintenance (O&M) savings of $1,916 million.[a] The corresponding numbers for the NGFC technology are $36 million first cost, $30 million NPV, an increase of 1.0 trillion Btu/yr in site energy consumption, and a present value of energy and O&M savings of $65.8 million. (Federally mandated life-cycle costing procedures and metrics are summarized in Appendix A.) The cost-effectiveness threshold or the breakeven electric energy price versus natural gas price (as defined from Appendix A) of an NGFC is shown in Figure 4. The two curves presented are based on initial investment costs taken from the manufacturer's current list price ($650,000 installed) and a reduced initial investment cost possible with Federal cost sharing of $1,000/kW ($450,000 installed). The breakeven analysis also assumes that 75% of the available thermal energy can be used to replace an existing thermal system that operates at 85% efficiency. Incremental natural gas and electric cost-combinations that fall below the breakeven curves are potentially cost effective. Energy prices for various representative sites are also plotted on the graph in Figure 4; they were taken from industrial energy costs reported in *Energy User News* (EUN March 1995a, 1995b).

Laboratory Perspective

Fuel cell technology has been the focus of both Federal and private-sector development for more than 30 years. Through theoretical analysis and laboratory testing, NGFC technology has been shown to be technically valid and economically attractive by virtue of it being a simple, reliable technology for direct electric energy conversion. NGFC systems can also provide thermal energy through heat recovery from the process of conversion from natural gas to electricity. Years of field testing and numerous demonstration projects have illustrated fuel cell system performance under various operational conditions. The

(a) The modified FEDS analysis gives estimates of aggregate net present value, installed cost, savings-to-investment ratio, and annual energy savings for a sample of Federal-sector facilities. These estimates are for the sample (Nemeth et al. 1993) only (which represents about 25% of the Federal building stock) and were not extrapolated to the entire Federal sector.

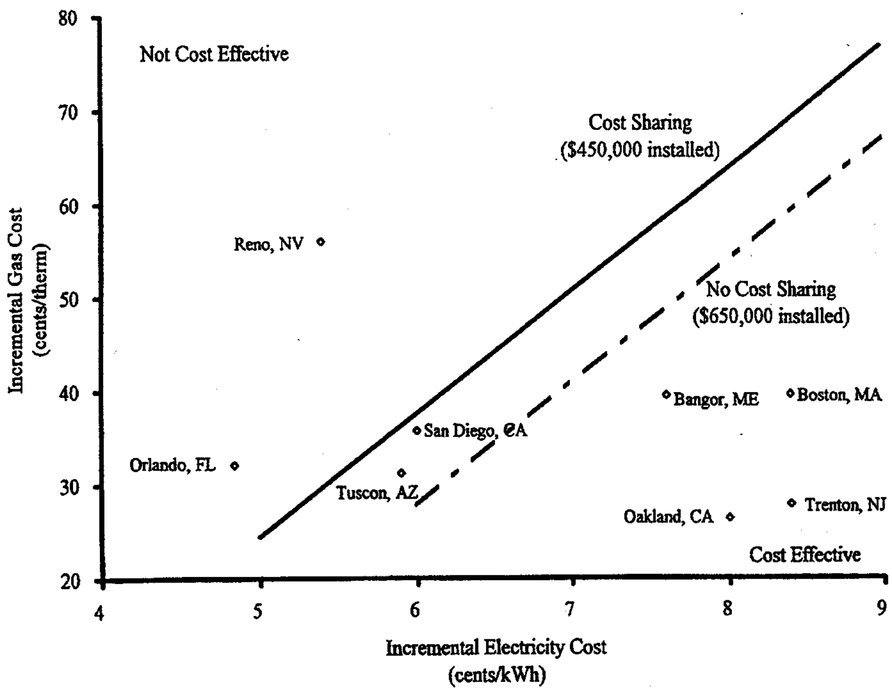


Fig. 4. Breakeven Analysis of a 200-kW Phosphoric-acid NGFC System

remaining barriers to implementation involve gaining user acceptance of this alternative energy production technology and reducing the initial cost of the NGFC. This *Technology Alert* is intended to address these barriers by reporting on the collective experiences of NGFC users and evaluators and by providing application guidance for Federal-sector applications.

Application

This section addresses general application aspects for NGFCs. The range of applications and environments in which the technology can best be applied are discussed. The advantages and limitations of each application are enumerated. Equipment warranties, maintenance costs, equipment costs, incentives, and other support are also discussed. In addition, a sample specification for a 200-kW phosphoric-acid NGFC is located in Appendix B.

Application Screening

An NGFC system is one of the most efficient fossil-fuel energy conversion systems available. It is also one of the cleanest electric-generating technology options that exist today for producing high-quality, reliable electric energy. As noted earlier, an NGFC can be applied as a prime power provider, an interruptible power supply, or as a cogeneration system. This *Technology Alert* considers the decision to apply or not apply an NGFC as primarily an economic matter. However, environmental regulations or power quality issues may also be influential.

As an economic alternative, an NGFC consumes natural gas and generates electricity and useful thermal heat. As a fuel-switching alternative, an NGFC allows the site to trade off between the cost of electricity and natural gas. However, the best applications appear to involve cogeneration. In a cogeneration application, the site offsets current energy consumption in some conventional system by reclaiming waste heat from the NGFC. The most common application identified is offsetting boiler energy consumption by preheating boiler feedwater or other hot water system. Although there are many load-control strategies that may be utilized, base loading the NGFC (operating continuously at full load) appears to be the most common and the most life-cycle cost-effective at this time. Other operating load-control strategies include peak shaving, electric-load following, thermal-load following, or economic dispatch.

Where to Apply NGFC

A full spectrum of electric energy requirements exists in the Federal sector. The following conditions may favor the use of an NGFC system:

- Where natural gas costs are low and electricity and demand costs are high (see Figure 4)
- Where the thermal energy can be recovered and utilized (the NGFC can become more cost-effective operating as a cogeneration system)
- Where compliance with increasingly stringent environmental air quality regulations is limiting the options available to meet electric power requirements
- Where electric power needs in remote areas are currently being met with combustion turbines or piston-driven generators
- Where critical electric loads are currently being supplied by high-cost uninterruptible power supplies, motor-generator sets, or backup generators running on fossil fuels

- Where critical electric loads require a continuous, uninterrupted electric energy source

- Where computers, telecommunications equipment, electronic security systems, or other electronic control systems demand a noise-free, highly reliable, high-quality electric energy source.

Because natural gas and electric costs vary significantly throughout the United States and because NGFCs can be applied in different configurations, Figure 5 presents a pair of breakeven curves for readers to make a quick estimation of the viability of an NGFC system at a specific site (given local energy costs). These curves are based on a total initial capital cost of $450,000 (installed) for a 200-kW system and assume that the thermal energy recovered is used to replace an existing thermal system operating at an 85% efficiency. In applying these curves, readers should ensure that the composite incremental energy costs used properly account for any and all seasonal cost rates, time-of-day cost variations, and annual demand charges.

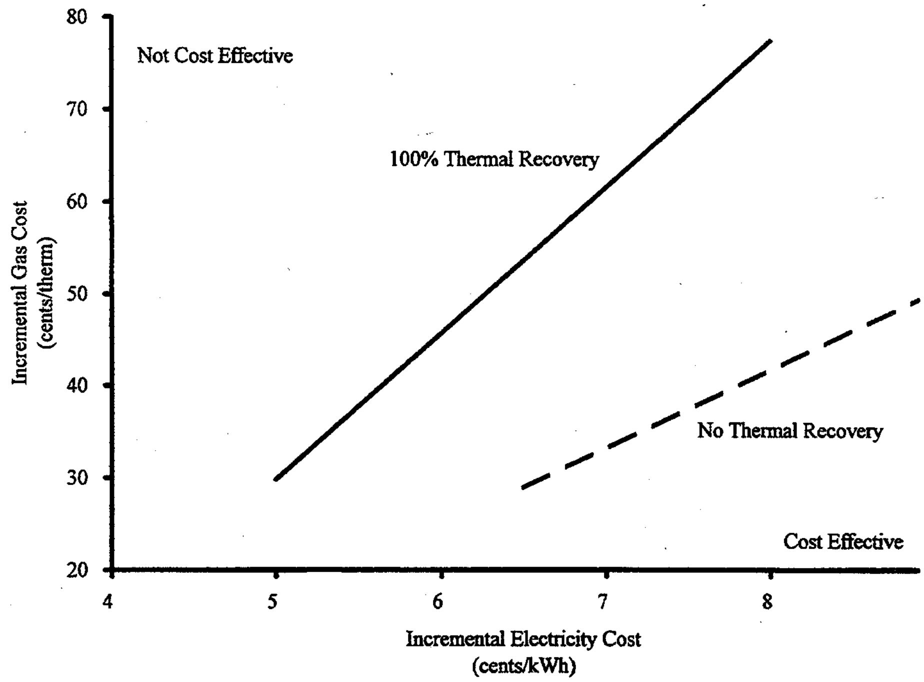


Fig. 5. When to Consider a 200-kW Phosphoric-acid NGFC System

What to Avoid

An NGFC system is most cost-effective when applied in a cogeneration configuration as a base load electric and thermal supply system. An NGFC system may not be as cost-effective under the following conditions:

- In a cogeneration configuration for use in either a thermal-load following or electric-load following control strategy. In these control strategies, the fuel cell loads and unloads and therefore typically operates at some part-load factor. Depending on the relative natural gas and electric costs, full-load operation (base loading) typically offers the best life-cycle-cost economics.

- For sophisticated thermal recovery and control systems that are designed to recover the maximum available thermal energy. A simplified thermal recovery system designed to recover most, but not all, of the available thermal energy can generally be designed and installed with lower first cost and lower life-cycle cost. "Keep it simple" is the best recommendation in designing the thermal energy recovery component of the overall system.

For selecting the NGFC application and installation design, it is important to keep the thermal-recovery system design as simple as possible. Complex thermal-recovery schemes significantly increase installation costs and can result in additional operation and maintenance costs. In most instances, thermal-recovery systems designed to recover and utilize around 75% of the available thermal energy result in cost-effective, highly reliable operating systems.

Equipment Warranties

One manufacturer provides a basic one-year limited warranty on parts and labor for the packaged components. Extended warranties and service agreements are typically available from the manufacturer at an additional cost. Annual routine maintenance and repair costs have been estimated by the manufacturer to run approximately $26,000/year (base 1995).

Costs

The costs of NGFCs are indicative of a technology proceeding through the development stage. When this *Technology Alert* was written, only one manufacturer had an NGFC commercially available. Several other systems were in the R&D stage or in various stages of field demonstrations. The current cost of the 200-kVA PAFC system is $600,000 ($3,000/kW), excluding installation. There is a Federal incentive program available through the U.S. Department of Energy (DOE) to reduce the cost of the fuel cell by $1,000/kW, thereby reducing the fuel cell cost to $400,000. This program is being managed through the DOE Morgantown Energy Technology Center (METC).

The history of equipment costs has shown significant price reduction as the commercial market grows and the technology matures. Initial 200-kW systems cost over $1.1 million each ($5,500/kW). The latest production is expected to cost around $600,000 ($3,000/kW). The cost is expected to drop even further in the future, when the unit costs are expected to be competitive with conventional power-generating equipment.

Installation costs also vary and are site-specific. It is estimated that the base system can be installed between $50,000 and $100,000 ($250 to $500/kW). Part of the reason for the cost variance is the heat recovery system and the variety of ways the thermal heat can be utilized. Options, site-specific issues, and experience will also affect installation costs.

Utility Incentives and Support

In many areas, gas utilities are eager to work with potential NGFC users because the installation of an NGFC means an increased base load on the natural-gas system. Some electric utilities may view the installation of an NGFC cogeneration systems in their area as a potential loss of market. Other electric utilities view NGFC systems as a viable system for distributed generation and welcome their installation. Readers should contact the local electric and gas providers in their areas to determine actual local utility support and/or incentives.

A number of companies have teamed with ONSI to bring the benefits of fuel cell power generation technology to a wide variety of clients. They include Enron Emerging Technologies, Inc. (Houston, Texas); ARIS, Inc. (Braintree, Maryland); Utilicorp (Kansas City, Missouri); and others. They have a system package designed to provide fuel cell power as a competitive option to end users (commercial buildings, hospitals, universities, government facilities) and to utilities. This power-production option is especially economical wherever potential users are faced with high costs associated with coal- or oil-generated electric power, where environmental constraints are stringent, or where transmission and/or distribution system load constraints limit growth and new installations are not possible.

Two Federal programs exist that can provide assistance to Federal utility and energy managers considering an NGFC. The U.S. Department of Defense (DoD) is providing funding through the CERL for the installation, monitoring, analysis, and evaluation of NGFC systems at selected DoD facilities in the United States. Readers interested in obtaining more detailed information on this program should refer to the individuals listed as Federal Program Contact Points later in this Technology Alert.

The Climate Change Fuel Cell Program (CCFCP) is funded through METC in coordination with the National Defense Center for Environmental Excellence. The CCFCP is a competitive, cost-shared, near-term effort that will provide up to $1,000/kW for the unit cost, installation, and pre-commercial operation of a 200-kW phosphoric acid fuel cell system from a U.S. manufacturer. Readers interested in obtaining more detailed information on this program should refer to the Federal Program Contact Points.

Technology Performance

In the United States, as this *Technology Alert* was written, 20 natural gas fuel cell systems had reportedly been installed in the private sector and 4 in the Federal sector. Observations on the actual performance obtained from Federal and private-sector users are summarized in this section (McClelland 1995).

Field Experience

Feedback from NGFC owners/operators on the systems performance has been extremely positive. System electric conversion efficiencies of 40% (based on LHV) and availabilities[(a)] of 96% or more are being reported on the latest models installed. The experience gained and the lessons learned from the commercial NGFC systems installed to date have conclusively validated the phosphoric-acid fuel cell technology. This knowledge base also has key elements applicable to the entire newly emerging fuel cell industry, which includes all fuel cell types previously noted.

The only negative feedback received dealt with the initial installation, permitting, and/or electric grid interconnection issues rather than actual system operation or performance. Two issues were raised regarding permits. One issue dealt with a local official who insisted that the internal wiring of the fuel cell be UL-certified and the other issue related to the need for a city permit on the gas-fired startup heater. These concerns and other potential areas for concern have been addressed by the manufacturer who obtained American Gas Association (AGA) certification

(a) The term *availability* is the ratio of actual run-time to scheduled run-time.

on the latest system model. The majority of issues or difficulties with installation are with the system connection to the local electric grid. Table 2 provides a summary, by owner, of owner experiences with electric grid interconnections (McClelland 1995).

Owner-operators have joined together to form an independent users group, the North American Fuel Cell Owners Group (NAFCOG), to share information on applications, siting, and installation. Operation and maintenance experiences are exchanged among users, and common feedback is provided to the manufacturer as suggestions for product improvement. Readers with an interest in installing and operating an NGFC are strongly encouraged to contact the members of this group. Contact names and phone numbers are listed under Who is Using the Technology, later in this Technology Alert.

Table 2. Electric Utility Grid Interconnect Experience

	Interconnection		Electric Utility Interconnection Issues	
Company	Type	Max. Site Voltage	Approval	Additional Requirements
(1) Southern California Gas	GPCS	1% low	1 year	None
(2) Southern California Gas	GPCS	4% high	6 to 8 months	None
(3) Southern California Gas	GPCS	4% high	6 to 8 months	None
(4) Southern California Gas	GPCS	4% high	6 to 8 months	None
(5) Southern California Gas	GPCS	4% high	6 to 8 months	User wanted U.S. MCB
(6) Southern California Gas	GPCS	4% high	6 to 8 months	None
(7) Southern California Gas	GPCS	4% high	6 to 8 months	None
(8) Southern California Gas	GPCS	4% high	6 to 8 months	None
(1) Commonwealth Gas	GPCS	Not available	Days	Non-export relay
(1) Equitable Resources	GP(DG)	11% high	1 month	None
(2) Equitable Resources	GPCS	4% high	2 months	None
(3) Consolidated Natural Gas	GPCS	6% high	4 months	None
(1) Peoples' Gas & Light	GPCS	6% high	2 months	Over/under voltage & frequency relays
(1) Minnegasco	GPCS	Not available	Few weeks	Non-export relay
(1) Jersey Central Power & Light	GI(PP)	Normal	2 months	None
(1) Gas Company of New Mexico	GPCS	Normal	Not available	Unknown
(1) Brooklyn Union Gas	GPCS	4% high	2.5 years	None
(2) Rochester Gas & Electric	GPCS	5% high	1+ years	Full duplicity of existing relays built into fuel cell
(3) National Fuel Gas	GPCS	Normal	8 months	Full duplicity of existing relays built into fuel cell

Notes: GPCS implies Grid Parallel on Customer's Side of the transformer
GI(PP) implies Grid Independent, Premium Power application
GP(DG) implies Grid Parallel direct to grid, simulating Dispersed Generation

Energy Savings

Annual energy cost savings vary widely and depend on the actual system application. NGFC applications have won two recent energy awards. A fuel cell power generating system at Saint Vincent's Hospital on Staten Island, New York, was designated the 1995 Cogeneration Project of the Year by the Cogeneration and Competitive Power Institute. The fuel cell is owned by Brooklyn Union Gas Company. The NGFC provides electric power to the hospital and supplies hot water to the hospital's laundry facility.

In addition, a power plant system consisting of two 200-kW NGFCs at the Riverside Medical Center in Riverside, California, won the 1994 Efficient Building Award for Energy and the Environment sponsored by Energy User News. The fuel cells are owned by the Southern California Gas Company. The two NGFCs provide continuous power to the hospital and provide hot water to the hospital's service hot water and heating, ventilating, and air-conditioning (HVAC) system. The fuel cells are expected to generate 3.3 million kWh/yr for the hospital. Thermal energy recovered from the system is expected to reduce natural gas consumption by 28,090 million Btu/yr. Annual reduction in utility costs is estimated to be $150,000/yr. The total cost to install the system at the time was $1.6 million. The project was a joint venture between Kaiser Permanente HMO Group, Southern California Gas Company, the Gas Research Institute, and the DOE (Gordon 1994).

At the U.S. Army's Natick Research, Development, and Engineering Center in Natick, Massachusetts, a 200-kW PAFC was installed as part of an overall DoD initiative demonstrating fuel cells. The system is expected to generate approximately 1,576,800 kWh/yr, saving the facility around $85,887 in electricity costs and $28,616 in demand costs annually. The thermal energy will be recovered to preheat boiler feedwater. The boiler currently burns No. 2 fuel oil, and the thermal recovery is expected to reduce oil consumption by 29,705 gallons/yr at a value of $21,548/yr. Operating the fuel cell is estimated to require 14,957.7 million Btu/yr in natural gas at a cost of $78,228/yr. Net annual savings in utility bill costs are estimated to be $57,823. At the time of construction, the 200-kW NGFC unit cost around $1.1 million, installation cost around $100,000, and a four-year warranty extended cost around $137,000 (Randazzo 1994).

The NGFC installed at the Pittsburgh International Airport (shown in Figure 1) is expected to save U.S. Air approximately $12,000 annually. The NGFC, operated by Peoples' Natural Gas, is expected to generate 1.6 million kWh/yr. The unit is expected to consume around 15,450 million Btu/yr in natural gas at a cost of around $60,000/yr. Thermal energy from the fuel cell is being recovered to supplement space heating requirements previously supplied by a natural gas boiler. With the thermal energy

Table 3. NGFC Emission Levels (units of ppmv, 15% O_2, dry)

Emission	Results (Limits)[a]	Typical Levels
NO_x	0.045 (3)	1
CO	1.40 (10)	5
SO_x	(b)	(b)
Particulates	(b)	(b)
Unburned Hydrocarbons	0.03 (250)	1

(a) Numbers in parentheses are SCAQMD's emission limits.
(b) Emission levels were either negligible or lower than detectable.

recovery, U.S. Air avoids 3,090 million Btu/yr in natural gas consumption for its boilers. The cost to install the NGFC was reportedly $900,000. The system was installed as part of a demonstration project by Peoples' Natural Gas (Randazzo 1993).

An installation at the St. Vincent's Medical Center in Staten Island, New York, is providing a net energy cost savings of approximately $70,000 annually. The system is owned and operated by Brooklyn Union Gas (Berry 1994). Thermal energy from the fuel cell is being recovered for use in the hospital's laundry facility.

Maintenance

An NGFC contains other systems and components in addition to the fuel cell stack that require routine maintenance. Water treatment beds and air filters require replacement every 3 to 4 months and do not require the system to be shut down. There are a number of pressure vessels, associated pressure relief valves and pressure piping systems that require annual inspection and testing. Routine annual maintenance typically requires a 2-day power plant shutdown. During this shutdown, motors, valve actuators, and protection functions can be checked and serviced as necessary. Four nitrogen cylinders, 235 standard cubic feet each, are required for each startup and shutdown cycle. The fuel cell stack and fuel processor require complete overhaul every 5 to 10 years. This is accomplished as a component change-out that requires a shutdown of several days. The replacement/overhaul of these major components is determined by the duty cycle, fuel composition, and load environment of the power plant. The manufacturer estimates planned and unplanned maintenance costs to be on the order of 1.5¢/kWh of system operation, or approximately $26,000/yr.

Environmental Impacts

There are no significant negative environmental impacts associated with NGFC technology. In fact, there are environmental benefits associated with operating an NGFC system. The South Coast Air Quality Management District (SCAQMD) in southern California conducted its own independent emissions testing of a PC-25™. Upon completion of the emissions testing, the SCAQMD granted NGFCs a blanket exemption from all air quality permitting requirements in the Los Angeles Basin area. Table 3 shows the emissions test results, along with the manufacturer's typical emission levels . The SCAQMD standards are also listed in parenthesis (Hirschenhofer 1995 and ONSI 1995b).

Exemptions have also been granted by the Santa Barbara Air Quality Management District, the Bay Area Air Quality Management District, and the state of Massachusetts. Other state and local air quality regulating bodies are considering similar actions (ONSI 1995b).

Exemption from air quality emission permits can be a significant economic incentive in the decision to install an NGFC system as a replacement for higher-polluting energy generation units. The operating costs associated with annual emission permits or with fines for non-compliance with permit limits could serve to reduce overall operating costs. Also, in some areas, the option exists to apply for a reduced-emission permit level for an existing emission permit and turn the reduction into an emission credit. These credits can be transferred to other sites where emissions or permits are a problem, or they may be sold to other organizations. The potential market value of these emission credits can be significant.

Case Study

The purpose of this case study is to assist the Federal energy or utility manager in estimating the energy consumption and life-cycle costs associated with the installation and operation of a natural gas fuel cell (NGFC) and comparing them with the life-cycle costs associated with a conventional energy system. The objective is to estimate the energy consumption and cost benefit associated with an NGFC cogeneration system.

Facility Description

A Federal facility in southern California is investigating the use of an NGFC in a commercial-type facility. The peak electric demand for the facility is typically around 1,000 kW, and the minimum demand is around 400 kW. The present annual electricity consumption for the facility is 5,256,000 kWh. The average facility load factor (LF)[(a)] for the facility is 60%.

In addition, the facility has a large service and process hot water system operating at around 140°F (60°C). The facility operates a natural gas-fired boiler continuously to meet the year-round hot water requirements. The boiler operates around 8,500 h/yr with the downtime scheduled for routine annual maintenance and inspection. The hot water requirement varies throughout the day. The boiler typically operates with a combustion efficiency of around 80%.

The local utility in this region is San Diego Gas and Electric (SDG&E), which provides both electricity and natural gas. The electric power for the facility is billed under SDG&E's General Service-Large-Time Metered, Schedule AL-TOU (secondary). Natural gas is billed under schedule GPTCI. The energy and demand costs are identified in Table 4.

Table 4. Summary of Case Study Energy Rate Schedules

Utility Charge	Summer	Winter
Natural Gas:	(Apr-Nov)	(Dec-Mar)
Energy (¢/therm)	35.185	36.622
Electricity:	(May-Sep)	(Oct-Apr)
Demand ($/kW-mo)		
Noncoincident	3.700	3.700
Coincident	17.520	4.070
Energy (¢/kW-mo)		
On-peak	7.698	6.902
Semi-peak	4.977	4.353
Off-peak	3.765	3.663

NGFC Equipment Selection

For the purpose of this example case study, the facility will consider the installation of a single 200-kW fuel cell operating in a cogeneration configuration. The fuel cell will be operated continuously at full-load for an estimated 8,500 h/yr. Waste heat from the fuel cell will be recovered and used to preheat water in the existing service hot water system. The existing boiler will continue to operate to meet the full requirements of the service hot water system.

Savings Potential

To determine the overall savings potential for this application, the reader must estimate a) the fuel cell energy consumption, b) the fuel cell electricity generated, c) the peak demand avoided, d) the boiler fuel consumption avoided, e) the operations and maintenance (O&M) costs associated with operating the NGFC, and f) any permit requirements, such as air quality/emissions. Estimating the consumption and cost parameters is simplified by assuming that the fuel cell operates in a base-loaded condition.

Natural gas fuel consumption is determined by the fuel cell's fuel consumption rate and the operating hours. Similarly, the NGFC operating at full-load will continuously generate 200 kW. The 200-kW NGFC consumes 1.9 million Btu/h (19 therms/h). Operating 8,500 h/yr, the NGFC will consume 161,500 therms/yr [(19 therm/h) x (8,500 h/yr)] and generate 1,700,000 kWh/yr [(200 kW) x (8,500 h/yr)]. The NGFC will also reduce peak demand by 200 kW each of the 12 months in operation, provided that the peak demand for the facility is not set during the scheduled downtime for the NGFC. It is good advice to contact the local utility when scheduling routine downtime, as well as informing them promptly of any unscheduled downtime.

Estimating boiler fuel savings can be difficult; it depends on site-specific issues and the reader's knowledge of the system operation. The objective is to determine how much energy can be recovered from the NGFC and utilized. Additional thermal energy requirements can be met with the existing boiler system, and excess thermal energy from the NGFC can be expelled using the cooling module. For purposes of this example, it is assumed that 75% of the recoverable thermal energy is actually utilized in the service hot water system. With that in mind, the boiler energy reduction can be estimated as follows:

Boiler fuel consumption avoided = (thermal energy recovery rate) x (part load factor) x (hours/yr) x (fuel unit conversion factor, if any) /(boiler efficiency)

The part load factor in this equation is the percentage of recoverable thermal energy that is actually utilized, 75% in this example. Therefore, the boiler energy consumption

(a) The facility load factor (LF) is determined by the average electric demand divided by the peak electric demand. From a facility electric bill, the facility load factor can be calculated by dividing the electricity consumption in kWh by the numbers of hours in the billing period and dividing that component by the peak electric demand in kW. LF = [(kWh)/(hours)]/(peak kW).

avoided is 55,781 therms/yr [(700,000 Btu/h) x (0.75) x (8,500 h/yr) x (1 therm/100,000 Btu) / (0.80)].

This means that while the fuel cell will consume 161,500 therms/yr, the boiler energy consumption will drop an estimated 55,781 therms/yr, for a net increase in natural gas consumption of 105,719 therms/yr. It is important to keep these two gas consumption figures separate. Depending on the local utility and local site conditions, the rate schedule available for the fuel cell natural gas consumption may be at a different (sometime lower) billing rate than the boiler's natural gas consumption.

Life-Cycle Cost

The total installation cost, including material, labor, equipment, overhead, and profit for the NGFC system, is estimated to be $650,000. However with the Federal cost share program, the net cost to the site is estimated to be $450,000.

The energy cost impacts can be determined by using the electric and natural gas rate schedules noted earlier and the energy consumption estimates calculated above. The value of the electric energy generated is $76,612/yr. The value of the electric peak demand avoided is $32,098/yr. The value of the boiler fuel consumption avoided is $19,894/yr, and the cost of the natural gas to run the fuel cell is $57,597/yr.

Using the guidance provided earlier in this *Technology Alert*, the O&M costs are estimated to be $26,000/yr. Emission and permit costs are site-specific and will therefore be excluded from this general example. However, readers should estimate current emission permit costs, such as for the boiler in this example, and anticipated emission permit costs, such as for the boiler (at reduced load) and the NGFC in this example. The reduction in local emissions may also reduce current air quality fines or make available emission credits which might be transferred or sold.

Through use of BLCC Life-Cycle Cost software (BLCC 4.20-1995), which is available from the National Institute for Standards and Technology (NIST), the total life-cycle cost for the NGFC alternative is calculated to be $1,908,188, compared with the conventional system with a life-cycle cost of $2,007,454, for a net-present value of $99,266. The savings-to-investment ratio (SIR) for installing the NGFC is 1.22. A comparison of the NGFC system with the conventional system using BLCC is illustrated in Figure 6.

Implementation and Post-Implementation Experience

The case study here is only an example of a typical NGFC installation as a cogeneration system. The actual implementation of NGFC technology, even in a cogeneration configuration, is unique to each site. Readers interested in a specific application are encouraged to contact the NAFCOG or the NGFC manufacturer's representative to identify an owner/operator with a similar application or installation.

The Technology in Perspective

Sir William Grove discovered the principle of the fuel cell in 1839; however, it took until 1992 for the first commercial system based on this principle to reach the marketplace. Today there are over 250 fuel cell systems in operation in at least 15 countries around the world.

The future of natural gas fuel cells in the Federal sector looks good. There are many potential applications for fuel cells, including prime power supply, interruptible power supply, and cogeneration supply. Because of the potential for reducing site emissions, improving power quality, and increasing power reliability, as well as the life-cycle cost economics, the market for NGFCs is anticipated to grow. As more fuel cell types and manufacturers enter the market, initial costs will drop, further enhancing the number of cost-effective applications.

The Technology's Development

Fuel cells have received significant attention in recent years because of their potential application as a highly efficient electric power-generating system with very low emissions. The technology's development has been driven by the DOE; and the Electric Power Research Institute, the Gas Research Institute, and their respective members are working together to provide support that will develop a market-pull for NGFC technologies. The DoD has joined suit and is now contributing significant support for stationary power plant demonstrations.

Today, only the phosphoric acid fuel cell is commercially available. The remaining three types (molten carbonate, solid oxide and proton exchange membrane) are still a few years away from commercial availability. Developers, however, are promising higher efficiencies and lower costs than the currently available fuel cell systems.

Relation to Other Technologies

NGFC technology is a viable, though currently somewhat more expensive, alternative to the use of internal combustion engines and gas turbines for mid-range electric power generation (Muller and Hirschenhofer 1995). Even though advancements in efficiency and reduction in emissions from combustion systems are being achieved, their conversion efficiencies and emission levels can never reach those achievable with NGFC technology.

Technology Outlook

The cost of a commercially available NGFC is currently $3,000/kW plus installation costs. Federal assistance of $1,000/kW is available at the present time. If Federal assistance programs are successful in increasing commercial sales, it is projected that system costs on the order of $2,000/kW could be reached in 2 to 3 years and should reach a level of $1,500/kW within the next 5 years (Sanders and Merkle 1995). As more fuel cell types become commercially available, this market competition should help drive prices even lower, possibly as low as $1,000/kW.

Manufacturers

As this *Technology Alert* was written, only one manufacturer offered an NGFC on the commercial market. Several other manufacturers were performing research, development, and testing; they should have units commercially available in 2 to 5 years, as noted in Table 1.

ONSI Corporation of
International Fuel Cells
195 Governor's Highway
P.O. Box 1148
South Windsor, CN 06074
Contact Point:
Fred Kemp, Manager,
Government Marketing
(203) 727-2212
(203) 727-2319 Fax

Who is Using the Technology

The list below includes contact points at both commercial and Federal-sector locations that already have the technology installed and operating. Most of the listed contacts are with the local gas and/or electric company that own the NGFC systems and are highly knowledgeable about installation, operation, and maintenance of NGFC energy systems. The reader is invited to ask questions and learn more about this new technology.

Operating Sites

Brooklyn Union Gas
Brooklyn, NY
Charles R. Berry (718) 403-3065
Unit Location:
Saint Vincent's Hospital

```
              NIST BLCC: COMPARATIVE ECONOMIC ANALYSIS (version 4.20-95)

              BASE CASE: Conventional(a)
              ALTERNATIVE: NGFC(b)

              PRINCIPAL STUDY PARAMETERS:
              --------------------------
              ANALYSIS TYPE: Federal Analysis--Energy Conservation Projects
              STUDY PERIOD:        20 YEARS (JAN 1995 THROUGH DEC 2014)
              DISCOUNT RATE:   3.0% Real (exclusive of general inflation)
              BASE CASE LCC FILE: CONV.LCC
              ALTERNATIVE LCC FILE: NGFC.LCC

                    COMPARISON OF PRESENT-VALUE COSTS

                                          BASE CASE:    ALTERNATIVE:    SAVINGS
                                          Conventional  NGFC            FROM ALT.
INITIAL INVESTMENT ITEM(S):               -----------   ------------   ----------
 CASH REQUIREMENTS AS OF OCCUPANCY               $0       $450,000     -$450,000
                                           ---------     ---------     ---------
      SUBTOTAL                                   $0       $450,000     -$450,000
FUTURE COST ITEMS:
 ANNUAL AND NON-AN. RECURRING COSTS              $0       $386,814     -$386,814
 ENERGY EXPENDITURES                     $2,007,454     $1,071,374      $936,080
                                          ---------     ---------     ---------
      SUBTOTAL                           $2,007,454     $1,458,188      $549,266
                                          ---------     ---------     ---------
   TOTAL P.V. LIFE-CYCLE COST            $2,007,454     $1,908,188       $99,266

         NET SAVINGS FROM PROJECT Conventional COMPARED TO PROJECT NGFC

            Net Savings  =  P.V. of non-investment savings       $549,266
                         -  Increased total investment           $450,000
                                                             -------------
                                           Net Savings:          $99,266

                      SAVINGS-TO-INVESTMENT RATIO (SIR)
                 FOR PROJECT Conventional COMPARED TO PROJECT NGFC

                        P.V. of non-investment savings
               SIR  =  -----------------------------  =   1.22
                         Increased total investment

                    ADJUSTED INTERNAL RATE OF RETURN (AIRR)
                 FOR PROJECT Conventional COMPARED TO PROJECT NGFC
                (Reinvestment rate =  3.00%; Study period = 20 years)

                              AIRR = 4.03%

                         ESTIMATED YEARS TO PAYBACK
                       Simple Payback occurs in year 12
                       Discounted Payback occurs in year 15

                            ENERGY SAVINGS SUMMARY
Energy           Units    ------- Annual Consumption -------     Life-Cycle
 type                     Base Case   Alternative    Savings      Savings
-------------    ------   ---------   -----------   ---------   ----------
Electricity      kWh      1,700,000             0   1,700,000   34,000,000
Natural Gas      Therm       55,781       161,500    -105,719   -2,114,380

 Note: the NS, SIR, and AIRR computations include differential capital
 replacement costs and resale value (if any) as investment costs, per
 NIST Handbook 135 (FEMP analysis only).
```

(a) File name for conventional power system (base case).
(b) File name for natural gas fuel cell alternative.

Fig. 6. Building Life-Cycle Cost (BLCC) Output

Commonwealth Gas
Fall River, MA
Peter McGrath (508) 481-7900
Unit Location:
U.S. Army Natick Laboratories

Consolidated Natural Gas
Pittsburgh, PA
Dick McClelland (412) 366-1000
Unit Location:
Pittsburgh International Airport

Equitable Resources
Pittsburgh, PA
Keith Spitznagel (412) 261-3000
Unit Locations:
Presbyterian Nursing Home, Pittsburgh
Riverview Nursing Home, Pittsburgh

Gas Company of New Mexico
Albuquerque, NM
Steve Casey (505) 241-4460
Unit Location:
Kirkland Air Force Base

Jersey Central Power & Light/GPU
Morristown, NJ
Steven B. Sanders (201) 455-8328
Unit Location:
AT&T Research Laboratory

Minnegasco
Minneapolis, MN
James Radford (612) 321-4337
Unit Location:
USAF Reserve Center

National Fuel Gas
Buffalo, NY
Betsy Herzog (716) 857-7890
Unit Location:
Riefler Concrete

Peoples' Gas and Light
Chicago, IL
Andrew Plonka (312) 240-7000
Unit Location:
Div. of Street & Meter Repair

Rochester Gas & Electric
Rochester, NY
Dan Rider (716) 724-8322
Unit Location:
Rochester Institute of Technology

Southern California Gas (9 units)
Los Angeles, CA
Terrence Hee (213) 244-3773
Unit Locations:
Hyatt Hotel, Irvine
Kaiser Hospital, Anaheim
Kaiser Hospital (2), Riverside
Kraft Foods, Buena Park
Santa Barbara Jail, Santa Barbara
SCAQMD Office Building, Los Angeles
University of California, Santa Barbara
Vandenberg Air Force Base, Vandenberg, CA

For Further Information

Federal Program Contact Points

Dr. Mike Binder
U.S. Army Corps of Engineers
Construction Engineering Research Laboratories (CERL)
Champaign, IL 61821-1072
1-800-USA-CERL

Larry H. Dubois
Defense Sciences (DSO)
Advanced Research Projects Agency
3701 North Fairfax Drive
Arlington, VA 22203-1714
(703) 696-2283

Jim Kimball
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Appendixes

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Appendix A

Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). A life-cycle cost evaluation computes the total long-run costs of a number of potential actions, and selects the action that minimizes the long-run costs. When considering retrofits, sticking with the existing equipment is one potential action, often called the *baseline* condition. The life-cycle cost (LCC) of a potential investment is the present value of all of the costs associated with the investment over time.

The first step in calculating the LCC is the identification of the costs. *Installed Cost* includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). *Energy Cost* includes annual expenditures on energy to operate equipment. (For example, a lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours (200 kWh) annually. At an electricity price of $0.10 per kWh, this fixture has an annual energy cost of $20.) *Nonfuel Operations and Maintenance* includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned out light bulbs). *Replacement Costs* include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable).

Because LCC includes the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

where PV(x) denotes "present value of cost stream x,"
IC is the installed cost,
EC is the annual energy cost,
OM is the annual nonenergy O&M cost, and
REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative's LCC is less than the baseline's LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$NPV = PV(EC_0) - PV(EC_1)) + PV(OM_0) - PV(OM_1)) + PV(REP0) - PV(REP_1)) - PV(IC)$$

or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

where subscript 0 denotes the existing or baseline condition,
subscript 1 denotes the energy cost saving measure,
IC is the installation cost of the alternative (note that the IC of the baseline is assumed zero),
ECS is the annual energy cost savings,
OMS is the annual nonenergy O&M savings, and
REPS is the future replacement savings.

Levelized energy cost (LEC) is the breakeven energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective (NPV >= 0). Thus, a project's LEC is given by

$$PV(LEC*EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS))/PV(IC).$$

Some of the tedious effort of life-cycle cost calculations can be avoided by using the Building Life-Cycle Cost software, BLCC, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 566-2877.

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Appendix B

Sample Specification for a 200 kW Phosphoric Acid Natural Gas Fuel Cell Power Plant

1.0 SYSTEM DESCRIPTION

The power plant is to be packaged as a self-contained, natural gas fuel cell plant capable of continuous operation at an electrical rating of 200 kW/235 kVA. It must provide a minimum of 700,000 Btu/hour of useful heat at full load at a temperature of not less than 140°F.

2.0 SYSTEM FEATURES

2.1 The power plant must have local operator interface capable of displaying measured or calculated system parameters such as but not limited to:

- Net Instantaneous Power
- Net Desired Instantaneous Power
- Load Hours
- Net AC Megawatt-hours
- Reformer Temperature
- Steam Accumulator Temperature

2.2 The power plant must have local diagnostic terminal that permits access to a comprehensive set of system parameters beyond that which is available via the local operator interface.

2.3 The power plant must have a modem that will allow remote data acquisition and control of the power plant.

3.0 PERFORMANCE CHARACTERISTICS

3.1 Standard Frequency and Voltage

<u>Frequency</u>	<u>Voltage</u>
60 Hz	480/277 Volts, 3-Phase, 3-Wire

3.2 Electrical Output Characteristics

Rated Load	200 kW/235 kVA
Power Factor Range	From 0.85 to 1.0 leading or lagging (adjustable 110% of rated RMS current integrated over 1 cycle)
Fault Current (RMS)	110% of rated RMS current integrated over 1 cycle
Maximum Line Voltage	±5% providing rated power +10% to -20% operating with kVA derated
Maximum Line Voltage	2% line-to-line at rated kVA
Unbalance Voltage Harmonics	THD < 3% at rated power when operating into a standard impedance of 4% inductive shunted by a 56% resistive load
Operating Power Range	5-100% of rated

3.3 Safety Features - Power plant must automatically transfer to idle mode (0.0 kW net) operation should a disconnect occurs because of an electric grid out-of-limit condition. The power plant must disconnect and/or interrupt operation if:

- Grid conditions exceed allowable for protection parameters listed below:
  AC over voltage
  AC under voltage
  AC voltage unbalance
  Loss of grid
  Synchronizing circuit failure
  Abnormal frequency
  AC overcurrent, instantaneous
  AC overcurrent, inverse time
  AC current unbalance
  Loss of synchronization
  Field adjustment and testing of protection functions
  Input port for site specific protection parameters

- Abnormal conditions last for more than 0.5 seconds or more than three interruptions occur in less than 15 seconds.

- The power plant must be capable of automatic reconnection if grid conditions are normal for a continuous 0-10 minute period (adjustable). This auto reconnect capability must have the option for user lockout of the feature.

3.4 Useful Heat Availability
Minimum Heat Output 700,000 Btu/hour at not less than 140°F at rated power

4.0 FUEL COMPOSITION LIMITS PIPELINE NATURAL GAS

4.1 Pipeline Natural Gas

Constituent	Maximum Allowable Percent Volume
Methane	100
Ethanes	10
Propane	5
Butanes	1.25
Pentanes, Hexanes, C_6+	0.5
CO_2	3
O_2	0.2
N_2	4
Total Sulfur	33 ppmv (6 ppmv average)
Ammonia	1 ppmv
Chlorine	0.05 ppm (weight basis)
Supply Pressure	4 to 14 inches water

4.2 The power plant must have the capability of using alternative fuels, such as propane, as an option.

5.0 ENVIRONMENTAL DESIGN CONDITIONS

Ambient temperature during operation -20°F to 110°F

	Site Altitude	
Operating Characteristic	Sea Level	6000 ft.
Maximum Steady State Power	200 kW	200 kW
Minimum Efficiency (LHV)	40%	39%
Grid-Connect Load Change		
0 to 200 kW	1.5 Sec	— —
0 to 155 kW	11.5 Sec	11.5 Sec
155 to 200 kW	3.5 Sec	20 Min

6.0 PHYSICAL SIZE LIMITATIONS (if any)

The power plant may be a modular system of up to two separate modules with no single module exceeding 10x18x10 feet. All modules must be capable of highway transport.

About the Federal Technology Alerts

The Energy Policy Act of 1992, and subsequent Executive Orders, mandate that energy consumption in the federal sector be reduced by 30% from 1985 levels by the year 2005. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) is sponsoring a series of programs to reduce energy consumption at federal installations nationwide. One of these programs, the New Technology Demonstration Program (NTDP), is tasked to accelerate the introduction of new energy-saving technologies into the federal sector and to improve the rate of technology transfer.

As part of this effort, FEMP, in a joint venture with the Department of Defense's Strategic Environmental Research and Development Program (SERDP), is sponsoring a series of Federal Technology Alerts that provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the Alerts have already entered the market and have some experience but are not in general use in the federal sector. Based on their potential for energy, cost, and environmental benefits to the federal sector, the technologies are considered to be leading candidates for immediate federal application.

The goal of the Alerts is to improve the rate of technology transfer of new energy-saving technologies within the federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their federal sites.

Because the Alerts are cost-effective and timely to produce (compared with awaiting the results of field demonstrations), they meet the short-term need of disseminating information to a target audience in a timeframe that allows the rapid deployment of the technologies—and ultimately the saving of energy in the federal sector.

The information in the Alerts typically includes a description of the candidate technology; the results of its screening tests; a description of its performance, applications and field experience to date; a list of potential suppliers; and important contact information. Attached appendixes provide supplemental informationand example worksheets on the technology.

FEMP sponsors publication of the Federal Technology Alerts to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant federal-sector savings, the Alerts do not constitute FEMP's endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. FEMP encourages interested federal energy and facility managers to contact the manufacturers and other federal sites directly, and to use the worksheets in the Alerts to aid in their purchasing decisions.

Federal Energy Management Program

The federal government is the largest energy consumer in the nation. Annually, in its 500,000 buildings and 8,000 locations worldwide, it uses nearly two quadrillion Btu (quads) of energy, costing over $11 billion. This represents 2.5% of all primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the federal infrastructure.

Over the years several federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; and, most recently, Executive Order 12759 in 1991, the National Energy Policy Act of 1992 (EPACT), and Executive Order 12902 in 1994.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting New Technology Demonstrations to hasten the penetration of energy-efficient technologies into the federal marketplace.

Strategic Environmental R&D Program

The Strategic Environmental Research and Development Program, SERDP, co-sponsor of these Federal Technology Alerts, was created by the National Defense Authorization Act of 1990 (Public Law 101-510). SERDP's primary purpose is to "address environmental matters of concern to the Department of Defense and the Department of Energy through support for basic and applied research and development of technologies that can enhance the capabilities of the departments to meet their environmental obligations." In 1993, SERDP made available additional funds to augment those of FEMP, for the purpose of new technology installations and evaluations.

For More Information

FEMP Help Desk
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International callers please use (703) 287-8391
Web site: http://www.eren.doe.gov/femp/

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