U.S. Coast Guard Research and Development Center

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Shore Facility Fuel Cell Demonstration

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NOTICE

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16. Abstract (MAXIMUM 200 WORDS)

A 250 kW Molten Carbonate Fuel Cell that converts natural gas into electricity was installed at U.S. Coast Guard (USCG) Air Station Cape Cod. The purpose of this evaluation was to determine whether fuel cell technology could be a reliable, environmentally friendlier, and cost-effective alternative to commercially procured electricity at CG shore facilities. This report discusses the installation and analyzes the fuel cell's performance for a one-year period beginning in June 2003. The fuel cell operated reliably; however, ancillary issues related to the utility interconnection required the fuel cell to operate at reduced power, which minimized cost savings. Even operating at reduced capacity, the costs of the fuel cell were $24 K less than the projected costs of equivalent commercially procured energy. Future savings will depend upon maintenance costs and the relative cost differential between natural gas and commercial electricity. If technological advances and savings from mass production can reduce capital costs in future years, fuel cells may become financially viable alternatives. They do provide a fairly reliable back-up power source, and significantly reduce emissions relative to other generating sources. Nonetheless, the technology has not yet matured to the point where it should be installed universally at other Coast Guard units.

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EXECUTIVE SUMMARY

The United States Coast Guard (USCG) has been exploring energy production that is less dependent on foreign fuels, less expensive, reliable, free of noise, and lower in emissions. One energy technology that promises to meet these criteria is fuel cells. To test whether fuel cells could be a viable alternative for USCG shore facility energy needs, the Research & Development Center (R&DC) completed a distributed generation fuel cell installation at USCG Air Station Cape Cod (ASCC). Under a contract with the Department of Defense, a study of several USCG shore facilities was undertaken. The barracks at ASCC, located on the Massachusetts Military Reservation, was selected as a test site based upon its electrical load requirements and its ability to utilize the fuel cell's recovered exhaust heat for domestic hot water and galley dishwasher water.

Due to the estimated costs, several grants were used to fund the project. These grants were obtained from the Department of Defense and the Massachusetts Technology Collaborative. The natural gas utility provider, Keyspan Energy, provided their connection services at no cost. A turnkey design, construction, manufacturing, and first-year service contract was awarded to PPL Energy Services Holdings, LLC. PPL employed a FuelCell Energy, Inc. 250 kW fuel cell (model DFC300A) with high-grade heat recovery for the domestic hot water. The USCG officially accepted the fuel cell installation on May 17, 2003.

Data analysis was conducted on the fuel cell's performance during the period June 1, 2003 through May 31, 2004. The results are mixed. From an availability perspective, the fuel cell has been operating reliably; however, ancillary issues related to the commercial electrical utility interconnection has required the fuel cell to be operated at significantly reduced power which in turn has minimized the amount of cost savings obtained to date. Even while operating at reduced capacity, the costs of operating and maintaining the fuel cell were less than the projected costs of procuring the energy commercially. This has resulted in modest savings for the period. Future savings will be dependent upon future maintenance costs and the relative cost differential between natural gas and commercially procured electricity.

A number of significant lessons were learned during this project regarding dealing with project teams, new technology, and data studies and analysis. These lessons have prompted the addition of a number of future work items. The completion of these work items may be necessary as a prerequisite for the ongoing viability of the fuel cell.

The lessons learned and results obtained to date indicate fuel cells are a rapidly changing technology and will likely be a prevalent source of power for a wide variety of applications in the future.

In many ways, the fuel cell evaluation at ASCC exceeded our expectations. It proved to be remarkably quiet, thus making it suitable for application in a crowded, noise restricted area. The emissions were also environmentally

friendly, and the power produced was of high quality and suitable for high technology applications.

However, the technology has not yet matured to the point where fuel cells should be installed universally at other USCG shore units. First, the technology has not proven reliable enough to serve as the sole electrical source for ASCC, nor has it proven itself to be an appropriate source of emergency power. The commercial electric utility and diesel fuel emergency generators presently have proven to be much more reliable than the fuel cell. Second, the fuel cell's capital costs are substantially larger than the cost of the other leading forms of distributed or emergency power generation. In some instances, when comparing capital costs of generators, a fuel cell can be twenty times more expensive. Finally, the costs of both annual maintenance and restacking appear to nullify projected fuel savings, thus making the fuel cell more expensive to operate in the short- and long-term environments. Fuel cell installations should be limited to high valued, niche installations where noise, power quality, or environmental concerns prevail.

Based on the results of this effort, the R&DC recommends against additional shore facility fuel cell installations at the present time. As the technology matures and the capital and maintenance costs lessen, fuel cells may become attractive for future USCG applications. Because of this, the technology should continue to be monitored for improvements. Also, the relative cost differential between natural gas and commercial electricity should be monitored since the cost differential between the two has the greatest impact on the cost effectiveness of the technology.

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Common Acronyms

Btu – British Thermal Unit
cf – cubic feet kW – kilowatt
DHW – domestic hot water
kVA – kilovolt amperes
LHV – lesser heat value
ppmv – parts per million volume
VAC – Voltage Alternating Current

ccf – one hundred cubic feet
cfm – cubic feet per minute
gph – gallons per hour
kWh – kilowatt-hour
MWh – megawatt-hour
scf – one thousand cubic feet

1 INTRODUCTION

1.1 What is a Fuel Cell?

Fuel cells are emerging as a leading energy technology with tremendous potential for fuel efficiency, environmental benefit and low maintenance. Unlike diesel engines that must burn fuel to produce heat, which in turn is converted by mechanical means into electricity, fuel cells electrochemically convert fuel in the form of hydrogen and oxygen to produce direct current (DC) electricity and water. There are no pollutants, and without Carnot Cycle limitations, fuel cell efficiencies can be considerably higher than conventional technologies. Currently, there is intensive development by manufacturers to market fuel cells for automobiles, residences and even consumer electronics. There are several types of fuel cells depending upon the nature of the electrolyte, and fuel cells come in power ranges from battery size to megawatt power plants.

Sir William Grove first demonstrated fuel cell technology in 1839. Through electrochemical processes vice combustion, fuel cells convert Hydrogen into DC electricity. With suitable pre-processing, fuel cells can also be fueled by other hydrocarbons such as methane, propane, compressed natural gas and even diesel fuel. With outputs primarily of water and carbon dioxide, they generally offer significantly lower emissions than either gas turbines or internal combustion (IC) engines. Fuel cells can be conveniently divided into low temperature and high temperature fuel cells. Advantages of the low temperature fuel cells are: lower size and cost, and faster startup and shut-down times, with efficiencies comparable to modern IC engines (40-45 percent). Advantages of the high temperature fuel cells are primarily higher thermal efficiencies (50-60+/- percent).

Conventional energy sources, such as the electrical power grid using natural gas, coal and fuel oil-fired systems, are the primary sources of electrical energy and heat for the Coast Guard today. Standby diesel generator sets are also common for units requiring emergency power. Although conventional systems consistently provide power, improvements are desired in reliability, availability, power quality, pollution, maintenance, and efficiency. These systems are mature in that they have been developed to a state where few significant improvements can be made to improve efficiency. If significant efficiency improvements in power production are to be found, they will have to come from alternative power sources or radically new technologies. Fuel cells may disrupt the conventional power paradigm with their potential for dramatic performance improvement.

One of the most promising fuel cell applications is distributed power. Distributed architecture electric power means that the power source is located near the end user, unlike conventional generating plants often located several hundred miles from the consumer. The advantages of distributed power generation include elimination of transmission and distribution losses that may account for up to 60 percent of a power bill, the opportunity to use new energy technologies such as fuel cells or micro-turbines, added power capacity to existing grids, and high power reliability. Many futurists argue that fuel cells will usher in a new "wireless" power infrastructure where "personal" power will eliminate the need for overhead power lines. As long as there is an appropriate fuel source, the end user will generate his/her own power.

1.2 Project History

Headquarters requested the R&DC investigate the potential benefits of using fuel cells for electric power generation. The request was based upon the need to address USCG energy objectives dating from 1997 that directed the Coast Guard to reduce facility energy costs from 1995 levels by 20 percent by 2005. The objectives further mandated CG facilities to "minimize the use of petroleum fuels in all its facilities and platforms...through investments in engineering." Since 1998, the U.S. Coast Guard Research and Development Center has been evaluating fuel cell technology for application throughout the Coast Guard. Several R&D initiatives to evaluate the potential of this new technology are underway such as the joint program with the U.S. Navy to develop marine power plants that operate on marine distillate fuels. Another fuel cell application that was investigated was the use of fuel cell power at the Cape Henry Lighthouse, Virginia.

Based upon Headquarters' request and the success of the Department of Defense's fuel cell program, the R&DC began investigating how the Coast Guard could acquire and evaluate a fuel cell at a shore facility. The Coast Guard's Facility Energy Manager in Civil Engineering Support, G-SEC, sponsored this effort. Funding of $80K was provided by internal R&D Select Project Funds to conduct the initial investigation. Initial efforts focused on installing a unit at the Coast Guard Academy or Air Station Cape Cod (ASCC). Later efforts examined LORAN Stations.

Along with meeting the CG Energy Objectives, locating a fuel cell at a CG facility was deemed to have numerous potential benefits, including:

- Independence from the National Electric Grid
- Environmentally Friendlier Power Generation
- High Quality Power Free from Fluctuations & Noise
- Reliable Emergency Power/Elimination of Emergency Generators
- Cost Effectiveness

The R&DC contracted with the U.S. Army Construction Engineering Research Laboratory (CERL) to conduct the site evaluations necessary to locate an appropriate location for a fuel cell installation. Working with its subcontractor, Science Applications International Corporation (SAIC), CERL conducted the fuel cell site evaluations at the USCG Academy and the ASCC. ASCC was chosen as the location of choice for the fuel cell installation due to site opportunities, economic feasibility and the need for reliable premium power independent of the grid.

The study of the ASCC reviewed several potential applications; however, Building 3159 (which contains the Bachelor Officer Quarters/Bachelor Enlisted Quarters (BOQ/BEQ) and the galley) was considered the only viable fuel cell site. As a basis for analysis the study utilized the following assumptions:

> "The fuel cell electrical interface at this building would be through a new 300 kVA transformer tied into the 208/120 V panel in the electrical room, or the 4160 V side of the existing building transformer. Fuel cell electrical output not utilized at Building 3159 would go into the base grid. Little to no power would be available for export to the commercial grid. Several thermal interface options were evaluated. These included domestic hot water (DHW) for the kitchen, DHW for the residents, space heating for the entire building, and combinations of these loads. Supplying all three loads resulted in the highest fuel cell thermal utilization at 52 percent. Supplying just the kitchen DHW load resulted in only a 13 percent thermal utilization. When interfacing with the space heating load and maintaining the DHW tank at its current 160 °F, a high-grade heat exchanger option for the fuel cell would be required. Total energy savings for a number of thermal interface options and two different natural gas suppliers were calculated. Annual energy savings ranged from \$49,109 to \$72,237 for the Colonial Gas (now KeySpan Energy) cases and \$83,775 to \$106,903 for contract natural gas purchase cases. A 20-year lifecycle cost analysis showed internal rates of return (IRR) of between zero and 12 percent based on a fuel cell cost of \$650,000." (Source: SAIC Feasibility Study)

Given the results of the study, and the potential for significant cost and energy savings, the USCG approached a number of agencies to solicit grants for the fuel cell effort. Of the agencies and organizations contacted, the Massachusetts Technology Collaborative (MTC), the Department of Energy, and KeySpan Energy provided funding and technical support for the installation. Simultaneously, the USCG was working with its designated prime contractor, PPL, to identify the appropriate fuel cell model to install at the location. Ultimately, FuelCell Energy (FCE), Inc.'s fuel cell model DFC®300A was selected.

Grant contributions were finalized and a contract between PPL and the USCG for the manufacture, installation, and first year's maintenance of the fuel cell was executed on September 24, 2001. As the prime contractor, PPL was responsible for all facets of the project. Within its own organization, it opted to complete the necessary design and engineering work for the on-site specific civil, structural, mechanical, and electrical specifications required for fuel cell installation. The balance of the work was completed by PPL through various subcontracts, including the primary subcontract with FCE for the manufacture, delivery, and installation of the fuel cell.

The manufacturing and design phases proceeded with minimal delays during the first half of the project. However, during latter stages of manufacture and fuel cell testing, a variety of issues arose which ultimately resulted in several delivery delays, and a number of contract modifications. Final installation and field testing was completed in April and May 2003. Final acceptance of the fuel cell was completed on May 16th, 2003. A thorough discussion of construction delays and modifications as well as system performance will be discussed at length later within this report.

2 SYSTEM OPERATIONS

The fuel cell system, as installed, serves a number of purposes. From an electrical standpoint, it serves as the primary power source for the operations section of ASCC when the commercial utility grid is operating properly. It also serves as an emergency power source for the barracks/galley building when the commercial utility is not online. In addition to providing electrical power, the fuel cell is currently configured with a heat exchanger that captures waste exhaust heat and uses it to pre-heat the galley dishwasher water and to heat the domestic hot water used throughout the barracks. Barracks space heating is accomplished using a separate system. The modes of operation and loads serviced are described in this section.

For clarification purposes, the USCG-maintained base on the Massachusetts Military Reservation consists of several different areas, including resident housing, base support, and operations. The fuel cell serves only the operations section. For purposes of this report, where ASCC or the USCG base is mentioned or referenced, the reference applies only to the operations section where the fuel cell is located/operating.

The primary purpose of the fuel cell's installation is to service all operating loads at the operations area of ASCC. The fuel cell's capacity was specifically sized to be less than the maximum load requirements for the base, and the need to continue to purchase a portion of commercial electricity was anticipated from the outset. During normal operation, the fuel cell is generating a certain portion of the total electrical energy being utilized and the balance is being purchased from the electrical grid. Additionally, connection to the commercial grid provides a source of backup power when the fuel cell is offline due to maintenance or mishap.

Determining the appropriate size fuel cell to install given the availability of commercial electrical power and expected and existing loads at the base required an in-depth study of the power loads and historical electrical usage. Maximum power usage is calculated using proven engineering calculations based upon the capacity of existing transformers. Another means to determine loads is to analyze historical utility.

In preparation for this project, the USCG contracted with the US Army Corps of Engineers (USACE) Construction Engineering Research Laboratory (CERL) to complete an evaluation of the loads at the base both from an overall feasibility standpoint and for determining the proper size of fuel cell to install. For purposes of its study, CERL used monthly utility data for one year and dedicated interval pulse data for the period March 20th – 27th, 2001. Based upon the CERL report, the loads for ASCC were anticipated to remain over 250 kW greater than 98 percent of the time. Given these results and the potential for future growth at the site, a 250 kW fuel cell was selected for the location. Unfortunately, as will be discussed later, the actual loads being encountered since the fuel cell has been installed are less than the anticipated loads. Additionally, the original design never included provisions to export excess electrical power produced by the fuel cell since base loads were expected to exceed the fuel cell's capacity more than 98 percent of the time. Furthermore, we erroneously assumed the fuel cell could be adjusted easily to lower output levels when load requirements were less than the fuel cell's maximum output.

2.1 Basic DFC 300A Fuel Cell Specifications

The key information for the installed DFC 300A fuel cell is included below.

Table 1. DFC 300A Fuel Cell Specifications.

Net Power Output /Power at Plant Rating	250 kW/375 kVA
Voltage	480 VAC 50 or 60 Hz
Net Electrical Efficiency at Rated Output	47% LHV
Heat Rate	7,260 Btu/kWh LHV
Fuel Consumption at Rated Output	32 scfm @ 933 Btu/cf LHV
Water Uptake	45 gph
Water Discharge	23 gph
Available Heat (at rated power)	Approx. 300,000 Btu/hr

2.2 Fuel Cell Inputs & Outputs

Unlike conventional fossil fuel combustion plants where fuel quality and prior preparation is of little or no concern, the inputs, quantity and quality of fuel to the fuel cell are of great importance. The basic inputs are natural gas, water, and air. The outputs are DC electricity, water, and exhaust gases consisting primarily of heated carbon dioxide and water vapor.

Fuel Gas – Natural Gas must meet fuel gas specifications and be provided at appropriate minimum pressures. Prior to conversion to electricity, the natural gas undergoes processing to remove odorants and impurities, is heated and humidified and is pre-reformed. High sulphur content is detrimental to the stack and must be removed in pre-treatment.

Water – Municipal grade water must be supplied to the fuel cell system. The primary function of the water is to raise the humidity of the fuel gas to the proper level to achieve the desired chemical/electrical reaction.

Air – Ambient air is filtered and preheated and is combined with the processed fuel gas for conversion.

Electricity – electrical output is noise free DC electricity that is conditioned and transformed into AC output.

Exhaust – Exhaust emissions contain predominantly nitrogen, water vapor and very low concentrations of carbon dixoide (10 ppmv), nitrogen oxides (NO_x) (0.3 ppmv) and sulphur dioxides (SO_x) (0.01 ppmv). The exhaust heat is used first for pre-heating purposes within the fuel cell itself. It is then piped through a heat exchanger where the waste heat is captured and used in the barracks' domestic hot water system. The exhaust gases are then vented to the atmosphere.

Water – excess water that is not used in the humidification of the fuel gas or that does not exit in the exhaust stream needs to be discharge-piped into the commercial wastewater or storm water system. Wastewater is clean discharge.

Additional interfaces to the fuel cell include electrical supply from the commercial utility or other appropriate sources for use in operating the fuel cell when it is not producing its own power, such as during start up times. A telephone or other communication line is also necessary to allow for dial-up access to the fuel cell's human machine interface (HMI) for remote monitoring and operation.

2.3 Safe Operating Modes

The fuel cell is designed to protect itself, and to some extent the external loads it services, by having several programmed safe operating modes. These modes and the triggering events are as follows:

Heat-Up Ramp Hold – During fuel cell heat-up, numerous conditions are monitored to ensure the system is functioning properly. If certain specified conditions are exceeded, the plant will hold at its current temperature to allow the system to reach equilibrium. Once the problem clears, either on its own or through operator intervention, the heat-up will continue.

Reduced kW Ramp Down – If certain parameters reach abnormal values during power generation in the grid connected mode, the plant power output ramps down to a pre-set level until either the condition clears or an operator intervenes. If the condition worsens or doesn't improve in a set period of time, the system switches to a more protective condition.

Hot Standby Step Down – If conditions that produced the reduced kW ramp down worsen or exceed the time parameters, the system will trip into hot standby and shed all generating electrical load while also reducing input flows to appropriate levels.

Emergency Shut Down – If certain sustained operating conditions or potentially damaging events occur, the fuel cell will undergo an emergency shutdown. In this event, all air and fuel flow to the stack ceases and nitrogen purges the stack to interrupt the chemical/electrical conversion.

The manufacturer considers the various conditions that cause initiation of one of the safe modes to be proprietary information. The downtime that may occur after one of these modes is directly related to the problem that needs to be resolved. In all cases, a change in mode will initiate a notification to FCE's customer service department. The representative can remotely dial into the system. In many cases, the representative has been able to quickly troubleshoot and correct the problem and have the system back into normal operating mode in a very short period of time. In most minor instances where the fuel cell is operating in a reduced kW mode or in hot standby, the system can be back to normal operation and electrical output in a matter of minutes after the solution has been resolved.

2.4 Normal System Operation

As mentioned, utilization of a certain portion of commercially provided electrical power was planned for and designed into the dual power system. With two power sources available, the design of the system had to account for appropriate sizing and connection.

The commercial electrical provider for ASCC is NStar. Commercial electrical power is provided to ASCC from NStar's point of service, located outside of the base boundaries, via an approximately 2,400' buried line. The conduit's base terminus is a 1000 kVA transformer that steps down the voltage from 13,200 V to 4160 V for distribution throughout the base. Additional transformers at the individual facility load points further step down the voltage from 4160 V to operational voltages ranging from 480 V to 120 V. The typical power loads at ASCC consist of building loads, communications and radar equipment, and light industrial equipment, such as pumps and power tools. The greatest individual electrical loads at the base are hangar lighting, hangar door electrical motors, and several compressors.

During normal operation, the fuel cell outputs power at its load set point. Within the fuel cell there are two breakers of note. The Customer Critical Bus (CCB) 52 provides power from the fuel cell to the barracks. Tie Breaker (TB) 52 connects the fuel cell to the remainder of the base loads. See electrical one line diagram (Figure 1). In normal operation, CCB and TB are closed, and power feeds from the fuel cell into the power control cabinet. The power control cabinet contains an automatic transfer switch (ATS) and power distribution block (PDB). The CCB connects through the ATS and powers Building 3159, the Barracks/Galley. TB connects through the PDB and provides power to the base loads. In normal operation, commercial power is used to supply all remaining loads above the production set point of the fuel cell. For example, if at a given moment, the fuel cell is producing 250 kW and base loads are 300 kW, 50 kW is being provided by the commercial grid.

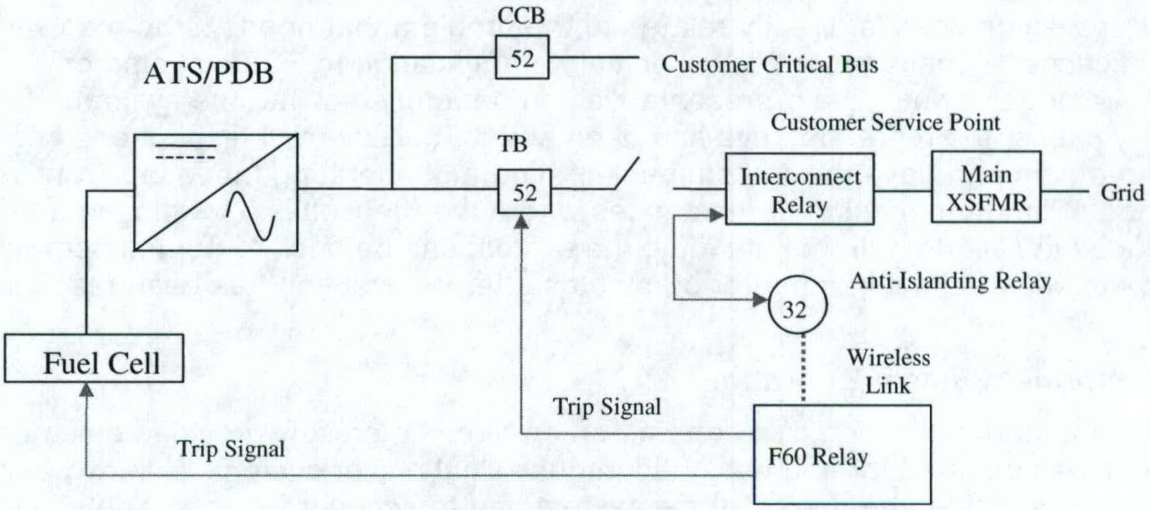

ONE LINE DIAGRAM FOR REVERSE POWER RELAY

Figure 1. Reverse Power Relay

2.5 Fuel Cell Normal Operation/Grid Outage

As a prerequisite for connecting to the grid, NStar required the USCG to install an “Anti-Islanding” or “reverse power relay” on the system. This system prevents power from being exported to the commercial grid when an outage occurs. The one-line diagram for the reverse power relay is depicted in Figure 1. When a grid outage occurs, the fuel cell is currently configured to provide power to only Building 3159.

The Reverse power device located adjacent to the USCG-owned 1000 kVa 23 kV/4160 V main transformer detects power export, and after a programmable time delay issues a trip command to TB via the radio master transmitter. The transmitter sends a signal to the slave receiver installed at the Fuel Cell Control cabinet. The receiver activates an interposing relay feeding a dry “NO contact” to the General Electric protective relay F60. The F60 will trip breaker TB. The plant goes into grid independent operation. The Fuel Cell production drops from its set point to 80 kW and provides power only to the barracks. Upon restoration of commercial power, the plant is reconnected to the grid. Other critical loads at the

Air Station, such as the hangars, currently obtain their emergency power from diesel generators. The addition of an energy management system that will connect the hangars to the fuel cell during emergency outages and eliminate the need for diesel generators is a potential future improvement project.

Unfortunately, the reverse power relay and NStar connection requirements currently restrict power from being exported at any time. Since the ASCC loads vary from day-to-day and hour-to-hour, the anti-export requirements imposed the need to reduce the Fuel Cell operating set point to a low enough point to ensure the fuel cell output never exceeds the base load requirements. To date, the production set point has ranged from a low of approximately 150 kW to its current operating high of 180 kW out of 250kW capacity. A further discussion of the interconnection process and associated issues will be discussed later.

2.6 Grid Normal/Fuel Cell Outage

When the fuel cell is offline due to either maintenance or mishap, the commercial utility grid will power the entire base. During the fuel cell outage, power to Building 3159 comes from the commercial utility via the PDB and ATS in the power control cabinet.

2.7 Dual System Outage

Unfortunately, during the rare instance when both the fuel cell and commercial utility are simultaneously inoperative, the only structures on the base with power will be the two hangars, barracks, sewage lift station, and the radar/communications systems. Power will be provided via the installed emergency diesel generators.

2.8 Thermal Loads

The DFC 300A Fuel Cell installation at ASCC is unique from the standpoint of its configuration as a combined heat and power (CHP) system. In addition to the electricity being produced, a high efficiency heat exchanger has been connected to the system to extract the waste heat from the exhaust gas. The heat exchanger helps to raise the total system efficiency approximately an additional 15 percent.

As configured, the waste heat is currently being to heat the domestic hot water to approximately 140 °F (60 °C). Upon demand, the 140 °F water is piped to the Galley dishwasher where it is further electrically boosted to wash temperature. The remaining DHW on demand is mixed with raw water to a temperature of 120° F (49° C) and distributed throughout the barracks. Additional studies of actual heat exchange, water usage, and flow rates are being undertaken. It is believed that enough additional heat is available once the fuel cell is operating at its 250 kW design capacity to pre-heat, if not thoroughly heat, the hot-water space heating system for all of Building 3159.

The existing boilers remain in place to provide the necessary building heat, make up hot water for the dishwashers, and to provide complete galley hot water on occasions when the fuel cell is not operating.

2.9 Basic Operating Checks

When the fuel cell is operating normally and with a maintenance contract in place for preventive maintenance and emergency repairs, the operator's responsibility for conducting basic operating checks is minimal. The operating checks and associated actions consist of:

1. Water Treatment Salt Level Gauge. Check gauge at least every three months. Add salt if low-level mark is reached.

2. Air Blower Filter Differential Pressure Gauge. Check every two weeks. Replace filter if "HIGH" indication is reached.

3. HVAC Unit Filter. Check every two weeks. Replace filter if dirty.

4. Stack Compression Nitrogen Tank Pressure Gauge. Check every two weeks. Notify manufacturer if sharp decrease in pressure is noticed.

Consumable supplies are readily available in standard sizes/grades/quantities from various commercial sources.

3 PROJECT BUDGET AND SCHEDULE

In order to complete an advanced technology undertaking such as the installation of a fuel cell system, identification and allocation of financial resources is one of the first of many keys required for project success. Although, there was significant interest in testing alternative energy systems, no single USCG entity was financially able to complete such an extensive and expensive system as proposed and ultimately installed at ASCC. Fortunately, a number of alternative funding sources were available both within the USCG and from outside sources.

Scheduling for a project undertaking such as this needed to consider both long- and short- term issues, such as coordination of resources and project partners, spiral development of new technology solutions, weather impacts on construction and the impacts of outside parties. The schedule changed quite frequently during the initial study and decision-making phases. Once the appropriate studies were complete, funding was identified and necessary government contracting completed. A contract was awarded to PPL to complete the turnkey project. FCE was used as the primary subcontractor. As in many large manufacturing and construction projects, the project did not progress exactly as planned in the original schedules. Due to a variety of reasons, the project schedule from commencement of engineering and design to commencement of operation expanded from 6 months to 18 months in duration.

Operating costs will be addressed in Section 7.

3.1 Contract Costs

The total contract costs for this project are stated in Table 2. The contract was set up with separate line items to coincide with the receipt of funds from the USCG and the various associated grantors. The line items followed the project completion in a chronological order and most items were awarded upon completion of the previous line item. The one exception to this rule was the line item for the manufacturing of the fuel cell, which was awarded as soon as funding was available.

Table 2. Breakdown of Contract Line Items*.

Contract Line Item (Original Cost)	Amount
1. Order Fuel Cell Power Plant	$450,000.00
2. Fuel Cell Installation Design	$58,200.00
3. Preliminary Site Work	$126,003.40
4. Manufacture Fuel Cell & Deliver	$612,500.00
5. Fuel Cell Installation	$439,211.00
6. Fuel Cell Operations Support	$23,610.00
Total	$1,709,524.40

*Does not include additional contract modifications

The contract line items do not necessarily provide a complete breakdown of the cost of the various constituent pieces of this project. Specifically, the line items do not necessarily portray the individual cost of procuring and installing a fuel cell without the additional costs necessary for a combined heat and power plant. For additional assistance in project planning and estimating, the line item costs can be further broken down based upon payment requests and other information approximately as follows in Table 3.

Table 3. Breakdown of Work Item Costs.

Project Breakdown	Cost
Fuel Cell	$1,250,000
High Grade Heat	$150,000
Engineering Services (5%+/-of cost)	$78,000
Site Preparation	$100,524
Installation/Start-up	$66,000
Project Management (4%+/- of cost)	$65,000
Total	$1,709,524

3.2 USCG Funding Sources

The USCG obtained funding for this project through several USCG sources. As in many organizations, responsibilities for engineering, utilities, research and development, and other functions are delegated to different offices or functional commands. Funds were obtained from the CGHQ energy manager, CGHQ civil engineering program manager, ASCC, and Civil Engineering Unit Providence, the local civil engineering support for ASCC. Through the concerted efforts of the various parties, nearly $1 million in funding was identified and allocated.

3.3 External Funding Sources

Given the nearly three-quarter million-dollar shortfall between contract estimate and available funding, the USCG sought additional funding through various grant mechanisms. The largest grant benefactor was the MTC who provided $406,000 from its Renewable Energy Trust funds. Under the U.S. Department of Energy's National Energy Technology Laboratory's Climate Change Fuel Cell Program, $250,000 was obtained. Keyspan Energy contributed $100,000 towards the project to fund the natural gas infrastructure upgrades necessary to provide fuel for the fuel cell.

Table 4. Project Funding Sources.

Funding Source	Amount
U. S. Coast Guard (Base Contract Amount)	$953,524.40
U. S. Coast Guard (Contract Modifications)	$123,740.00
Massachusetts Technology Corporation	$406,000.00
U. S. Department of Energy	$250,000.00
Keyspan Energy	$100,000.00
Total Contract Cost including Modifications	$1,833,264.40

3.4 Project Modifications

This project proceeded with relatively few contract modifications considering the uncertainty associated with the new technology. Based upon experience with other USCG construction projects, a 7.4 percent modification rate is an average value for construction modifications. Notably, $62,000 of the modifications, approximately one-half the value, was associated with optional work the CEU and ASCC chose to complete to save in later construction costs. The $4,740 additional boiler services modification resulted primarily from miscommunication between the contractor and USCG personnel on site. The remaining $60,000 modification for the interconnect requirements resulted from the cost uncertainty encountered in the initial design. For future projects, the interconnection requirements and costs should be determined at the project's inception and included as part of the complete design drawings, specifications and cost estimate.

Table 5. Project Modifications.

Modifications	Amount
Replacement of Building 3159 hot water tank and design change for relocation of drain lines*	$58,200.00
Drain line relocation site work*	$3,800.00
Additional temporary boiler services	$4,740.00
Interconnect design and installation	$60,000.00
Total	$126,740.00
Modification Rate	7.4%

*Denotes additional work completed at the request of ASCC but not required nor directly related to the fuel cell installation.

3.5 Project Schedule

The baseline project schedule and the actual project performance are included below. The baseline project schedule was developed during the contracting and funding phase of the project. Final grant pledges and acknowledgements were received from the U.S. Department of Energy, MTC, and Keyspan Energy throughout September 2001, and the actual contract award to PPL occurred on September 24th. A contract kickoff meeting was held at ASCC on October 3rd. Final acceptance was completed on 17 May 2003. A complete project chronology including the associated delays is included as Appendix A.

Table 6. Planned & Actual Project Schedule.

Major Project Milestone	**Baseline Date**	**Actual Date**	**Variance**
Start Engineering & Design	04 Oct 2001	04 Oct 2001	None
Design Review Meeting	29 Nov 2001	29 Nov 2001	None
Final Design Complete	13 Dec 2001	18 Apr 2002	126 Days
Commence Site Preparation (slab, piping, etc.)	18 Mar 2002	29 Apr 2002	42 Days
Fuel Cell Fabricated, Tested, & Delivered	17 Apr 2002	14 Mar 2003	331 Days
Finish Site Preparation	19 Apr 2002	13 Jun 2002	55 Days
Complete Fuel Cell Installation	01 May 2002	14 Mar 2003	318 Days
Start up Fuel Cell	02 May 2002	27 Mar 2003	330 Days
Begin Acceptance Testing	02 May 2002	13 Apr 2003	347 Days
Fuel Cell Accepted & On Line	15 May 2002	16 May 2003	366 Days
Commence First Year of Operation	16 May 2002	17 May 2003	366 Days

4 PROJECT CHALLENGES

Much can be learned from this project by looking at the process undertaken to install the fuel cell and by reviewing system performance and characteristics. However, the manner in which obstacles are overcome to ensure the project's success can provide the greatest insights. There are three predominant challenges that occurred during this project that warrant reiteration. These problems include the interconnection to the grid and the associated interactions with NSTAR, the fuel cell's manufacturing and testing delays, which resulted in the one-year delay in project completion, and the lower than anticipated loads at the station.

4.1 Commercial Utility Interconnection

4.1.1 Problem

Although masked by the other project delays, the lengthy time required to complete the interconnection agreement with the commercial utility company could have potentially resulted in serious project impacts if the remainder of the project had been completed on schedule. Although project representatives met with utility early in the process, the length of time required, the review process, and the apathy on the part of the utility was not anticipated.

4.1.2 Solution

Relentless pursuit of an answer by all associated parties was key to obtaining interconnect approval from the utility. Other steps that could have helped expedite the situation would have been to ensure a complete understanding of the process the commercial utility uses to review and approve requests, and to adhere entirely to these processes. Additionally, the project partners erroneously assumed the utility would be interested in assisting in this endeavor. If the utility could have been shown why their participation would have been beneficial or profitable for them, the utility may have responded more expeditiously.

4.1.3 Problem

The future success of the project hinges on the ability to run the fuel cell at design capacity for the maximum time allowable. As shown by the operational results to date, the current per kWh cost of fuel cell energy is approximately 1.5 cents per kWh less than utility provided electricity even though the fuel cell is producing at reduced capacity. Of course this is based upon current fuel costs and the contract cost of the first year's maintenance. Unfortunately in subsequent years as maintenance costs increase, the cost of electricity produced by the fuel cell may outstrip the costs of commercially procured electricity. These effects will be magnified substantially if the fuel cell is operating at lower than maximum capacity. To operate at maximum capacity, the USCG must complete an agreement with the commercial utility company to allow the export of excess energy.

4.1.4 Solution

The solution for the interconnection issue lies both in engineering and in relentlessly interacting with the commercial utility. Fortunately, the engineering is easily solved and is solely dependent upon identification of the approximately

$25,000 estimated design and installation costs. Reaching an agreement with the utility will hopefully be less cumbersome than the first time, since the partners are familiar with both the process to be followed and people to contact. In addition, the IEEE published national interconnection standards in July 2003. Given the existence of an approved industry-wide standard to follow, it will be much easier to ensure compliance of solution or to reject unusual requests by the utility.

4.2 Manufacturing & Testing Delays

4.2.1 Problem

The one-year delay associated with manufacturing and installation was a significant hurdle to overcome. Since this project was a research and development initiative, which frequently contains higher levels of risk and uncertainty, it is unclear what additional steps could have been taken. However, one point worth emphasizing is in any project lengthy delays can result in strained project partnerships and customer-client relationships. Extra communications efforts on the part of contractors should occur in order to alleviate concerns and doubts and manage client expectations.

4.3 Lower than Anticipated Loads

4.3.1 Problem

Lower than anticipated load utilization requires the fuel cell to be set at lower operating outputs to avoid exporting power to the commercial grid.

4.3.2 Solution

The lower than anticipated loads issue has been addressed in detail in several sections of this report, so it will not be covered in great detail here. However, it is valuable to reiterate some key issues. First, ensure complete utility studies are undertaken which look at usage for lengthy periods of time. Ensure, the studies do not weigh too heavily on average figures, but look for daily extremes as well since these extremes may control design and output. Second, ensure partners fully understand the operation of both existing and proposed systems. This ensures troubleshooting can be completed promptly. Finally, take advantage of internal and external expertise both during planning and operational phases to help identify and solve problems.

A complete discussion of lessons learned is included in Appendix B.

5 SYSTEM PERFORMANCE

The system performance to date can be characterized best as having mixed results. The pattern of electrical load at the air station combined with the electric utility's requirement to avoid export of power onto the commercial grid has resulted in restricted operation of the equipment. The fuel cell has been set between 150 kW and 180 kW depending on ASCC conditions. At this level of fuel cell production, the air station has to rely on the commercial utility for a larger portion of its power than originally planned. The typical load pattern results in the utility supplying between 20 kW and 180 kW, as illustrated in Figure 2.

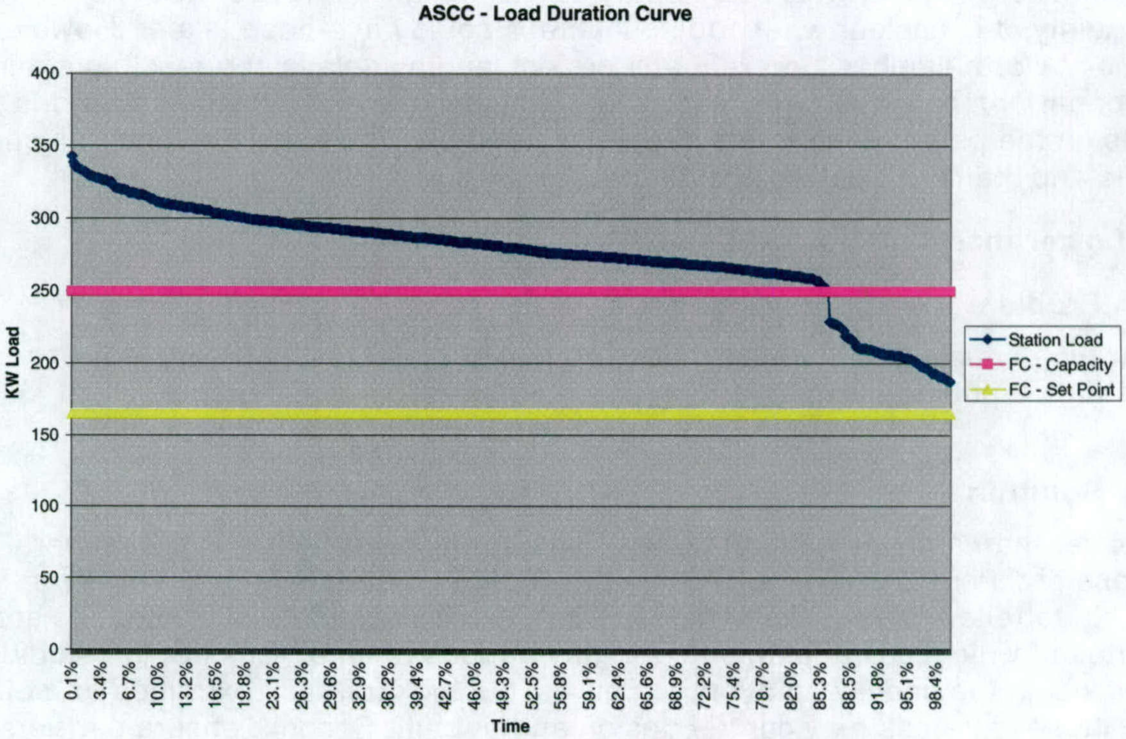


Figure 2. ASCC Load Duration Curve

Under the current operating procedure, the fuel cell will produce about 60 percent of the operations section of the air station's power requirements. The remaining 40 percent will continue to be purchased from the utility. If the fuel cell was operated at full capacity (250 kW) and the utility allowed export of up to 80 kW for about 1,000 hours per year (roughly 52,000 kWh per year or less than 2.5 percent of the total annual capacity), the fuel cell could displace about 90 percent of the power purchased from the utility.

5.1 Operational Availability

During the analysis period, the fuel cell was available for 8,449 hours of the 8,784 total hours available for an overall availability factor of 96.2 percent. The expected availability for the period was 95 percent, so the fuel cell exceeded expectations in this category. From an electrical standpoint, the restrictions against power export to the commercial grid have had a significant overall impact on the production and resulting costs. However, from strictly an electrical Operating & Maintenance (O&M) cost standpoint, the fuel cell production resulted in net cost savings during the period. Unfortunately, these savings were somewhat minimal and had very little impact on defraying the capital expenditure. Regarding the thermal utilization of the fuel cell's exhaust heat, performance data is somewhat elusive due to difficulties in separating consumption data from fuel bills and determining actual heat exchange due to missing heat exchange monitoring and flow metering data. A Btu meter was recently installed to monitor the heat collected from the exhaust by the heat exchanger. Subsequent analyses will use this information to more accurately determine thermal performance. However, for this report, estimates of thermal performance have been provided based on best available data.

Although electrical and thermal performance are discussed separately and treated independently, the success of the fuel cell is ultimately dependent upon both. Although at times the costs for electrical production using the fuel cell may exceed the costs of procuring the electricity from the commercial utility, one must remember to factor in total power efficiency and fuel utilization when determining total cost effectiveness. Table 7 provides a monthly breakdown of availability.

Table 7. Monthly Fuel Cell Availability.

Start Date	End Date	Total Hours	Generating Hours	Outage Hours	Availability %
6/1/2003	6/30/2003	720	710	10	98.6
7/1/2003	7/31/2003	744	744	0	100.0
8/1/2003	8/31/2003	744	734	10	98.7
9/1/2003	9/30/2003	720	718	2	99.7
10/1/2003	10/31/2003	744	739	5	99.3
11/1/2003	11/30/2003	720	708	12	98.3
12/1/2003	12/31/2003	744	736	8	98.9
1/1/2004	1/31/2004	744	723	21	97.2
2/1/2004	2/29/2004	696	648	48	93.1
3/1/2004	3/31/2004	744	662	82	89.0
4/1/2004	4/30/2004	720	583	137	81.0
5/1/2004	5/31/2004	744	744	0	100.0
	Totals	8784	8449	335	96.2

Individual fuel cell outage hours were analyzed to determine cause and duration. The results are included in Table 8. During the evaluation period, there were 18 shutdown events. Two events were planned maintenance or system upgrade outages and totaled three hours. The remaining outage events were unplanned.

Table 8. First Year Shutdown Events and Affected Hours.

Incident			Outage Type		Outage Cause							
Date	Description	Hours	Planned	Unplanned	Grid	Unknown	Software	Water System	AT-230	Inverter	XV-301	Other
6/23/2003	Water	10		X				X				
8/4/2003	F-60 Under	4		X	X							
8/7/2003	Water System Upgrade	3	X					X				
8/28/2003	Grid Disturbance	3		X	X							
9/22/2003	Software Upgrade	<1	X				X					
9/26/2003	ESD/ATS Trip	2		X					X			
10/10/2003	Grid Disturbance	5		X	X							
11/14/2003	Undetermined	7		X		X						
11/18/2003	Undetermined	5		X		X						
12/12/2003	Undetermined	8		X		X						
1/15/2004	Lower invert ambient temp.	15		X						X		
1/15/2003	XV-301 Leak	6		X							X	
2/9/2004	Grid Disturbance	18		X	X							
2/9/2004	XV-301 Leak	30		X							X	
3/12/2004	Compartment Fan Failed	6		X								X
3/26/2004	Grid Disturbance	11		X	X							
3/26/2004	Failed Fuel	65		X								X
4/8/2004	Desulfurizer Replacement	137		X								X
	Total	335	3	332	41	20	<1	13	2	15	36	208

The most significant outage event resulted from the need to replace the activated carbon in the desulfurizer. Although the carbon change was not expected to be completed until the 18 month maintenance service, regular testing of the material indicated the carbon had already reached saturation. Further operation of the fuel cell without replacing the carbon would have allowed the damaging introduction of sulfur into the stack. Since carbon replacement was not expected until the 18-month interval, replacement material was not on hand and proved to have a longer procurement time than expected. As a result, the fuel cell was offline for 137 hours. Fortunately, future occurrences of this situation will be easily avoided by more frequent testing of the carbon bed and by maintaining adequate replacement material in inventory.

Repairs to the main fuel valve and fuel vent valve accounted for 101 hours. Sixty-five of the valve related outage hours can also be partially attributed to a failure of the remote monitoring system which, for an undetermined reason, did not notify FCE of both a concurrent grid disturbance and valve problem. As a result, by the time FCE was notified of the problem, the plant had undergone an emergency protective shutdown.

Grid distrubances caused the protective relay to open in five cases resulting in 41 outage hours. Normally, grid disturbances result in island mode operation, but in these cases the plant shut down. These outages were later attributed to internal software issues which have since been resolved.

The remaining outage hours can be attributed to a variety of causes and were generally short in duration. Since the minor outages have decreased with the maturing of both the plant and operators, the outages are best considered the result of the minor "tweaking" of a new system or installation such as happens with many mechanical systems.

Although the overall availability rate of 96.2 percent exceeded the expected design rate of 95 percent, the system's performance could have been even better. If the 137 hours expended on carbon replacement had taken a more reasonable period time, the availability would have readily exceeded 97 percent.

5.2 Electrical Performance

The design electrical performance expectations for the DFC 300A are outlined in Table 9. A synopsis of the key performance results is included in Table 10.

Table 9. Design Electrical Performance Expectations.

Power at Plant Rating	250 kW
Operating Availability (Time)	94% - 98%
Avg. Monthly Gross kWh Output	174,000 (Assuming 95% Availability)
Parasitic Load kW (Hourly)	17-20
Capacity Factor	0.92 - .96 (reduced due to ramping/maintenance)
Electrical Efficiency	45%
Utilization of Available Power Output	100%

Table 10. Actual Electrical Performance Expectations.

Power Set Point	150 kW to 180 kW	Varies due to export restrictions
Average Operating Availability	96.2%	Hours Operating/Total Hours
Gross Electricity Produced	1,392,412 kWh	
Net Electricity Delivered	1,250,174 kWh	Gross – Power to run DFC300A
Total Hours Operating	8449	
Total Hours Standby	335	Note: Hours not delivering electricity
Average Operating Set Point	155 kW	
Electrical Capacity Factor	0.569	Actual Delivered kWh/kWh Possible (250 kW*8784 Hrs)

During normal operation, the fuel cell was set to deliver on average 150 kW to 160 kW to the ASCC. As discussed previously, the current interconnection requirements with the commercial electrical utility prohibit power export to the grid. Due to the fluctuating nature of loads and lower than expected overall loads at the facility, the fuel cell was set at the lower operating set points vice 250 kW. Table 12 demonstrates the impacts of operating below design capacity. As can be seen, the lost power production caused by the lower set point exceeds 700,000 kWh, or more than one-third of the total capacity. Efforts are continuing to revise the interconnection design and agreement to allow for minimal power export and net metering at the facility. These improvements, once completed, will have a significant impact on production level, electrical efficiency, and overall system costs.

As a distributed energy source, the fuel cell is designed to operate independently of the commercial utility grid. When this occurs, it is known as operating in “Island Mode.” When in Island Mode, the fuel cell disconnects from the utility grid and operates at 80 kW to produce power for the barracks. During the evaluation period, 21 Island Mode events occurred totalling 316 hours, see Table 11. Interconnect equipment problems caused 208 hours of Island Mode operation during the early stages of the installation. During September 2003, the fuel cell was manually set to operate in Island Mode for 66 hours as a precaution against power failure from Hurricane Irene. The hurricane never approached ASCC, but the system performed well during the period. The remaining 42 hours are attributed to issues with the commercial grid or unknown causes. Although the grid did experience 42 known hours of failure last year, there were a number of occasions when the power would be briefly interrupted and cause the fuel cell to trip into Island Mode. Due to the manual nature of resetting the connection, frequently the fuel cell would remain in Island Mode for a number of hours before the link was re-established.

Table 11. Island Mode Causes & Durations.

Island Mode Incident		Cause				
Date	Hours	F60	Reverse Power Relay	Radio Failure	Manual	Grid or Unknown
6/5/2003	4					X
6/9/2003	3					X
6/14/2003	3					X
6/16/2003	4					X
6/20/2003	3					X
6/24/2003	9					X
6/25/2003	195			X		
7/12/2003	2			X		
7/16/2003	2			X		
7/26/2003	1		X			
8/27/2003	2					X
9/8/2003	3					X
9/17/2003	66				X	
10/2/2003	1	X				
10/15/2003	3	X				
10/19/2003	2	X				
10/26/2003	2	X				
11/13/2003	2					X
12/6/2003	2					X
12/14/2003	2					X
4/6/2004	5					X
Total	316	8	1	199	66	42

Table 12. Lost Electrical Production.

Description	Hours	kWh	Percent
Loss due to Availability	335	83,750.0	3.8
Loss due to Island Mode	316	55,300.0	2.5
Loss due to set point	8133	772,683.3	35.2
Loss on startup/shutdown		34,092.7	1.6
Actual Production		1,250,174.0	56.9
Total Possible Production	8784	2,196,000.0	100.00

5.3 Electrical Production Successes/Concerns

A review of the available data to date indicates a number of successes and raises a number of concerns for the use of fuel cell technology.

From a positive standpoint, the fuel cell's average availability during the period was nearly ninety-six percent, exceeding the anticipated and design ninety-five percent availability. Additionally, the total average fuel cell production cost of electricity was about 1.5 cents lower per kilowatt-hour than commercially provided electricity.

Although power output is limited during normal operation due to the lack of load to displace, the fuel cell functioned as a grid independent/emergency power source. During the testing period, several short grid outages occurred, and in most instances, the fuel cell operated normally and automatically assumed the power load for the barracks/galley while commercial power was being restored. A more significant test of the emergency power aspects of the system occurred September 17th through September 21st, 2003. During this period, the fuel cell was placed into grid independent mode as a precaution against loss of the commercial utility during a potential hurricane. Fortunately, the storm passed well west of the area, but the fuel cell operated as designed during the period and helped prove its potential value as an emergency or independent power source.

Unfortunately, the inability to operate the fuel cell at rated capacity has both current and future ramifications. To begin with, the operating set point for the fuel cell has been running at roughly 60 percent of the rated capacity. Unfortunately, the fuel cell realizes its maximum level of efficiency when operating at or near its design rating. The current operating set point efficiency is lower than the level of maximum efficiency. In addition to reduced efficiency, the lower set point means that a greater portion of commercial electrical energy has to be procured.
An additional and possibly greater concern for the future is the actual cost of natural gas, the cost of future fuel cell maintenance, and the resulting

impacts on the cost of fuel cell produced electricity. Natural gas prices are set by the levels of supply and demand in the market and are out of the control of the USCG. Fuel cell maintenance costs are subject to negotiation between the government and the provider. As a new piece of equipment, maintenance costs are likely to be higher until the provider gains experience and more equipment is deployed in the market.

During the initial project feasibility study phase, the cost of natural gas was anticipated to be on the order of $0.508 to $0.867 per CCF depending on the season of the year, summer being less expensive. Commercial electricity costs were estimated to be on the order of $0.0913 per kWh. At these initial cost estimates, the fuel cell was estimated to rapidly accumulate savings to defer maintenance costs and recoup capital expenditures. Unfortunately, the actual costs to date for natural gas have been approximately $1.11 per CCF, a greater than 100 percent increase from the study's anticipated summer prices and an increase of 28 percent when compared to winter prices. Commercial electricity at $.1114 per kWh has only increased 22 percent from the initial study. Although operating savings are being realized at current prices, a further increase in natural gas prices could easily reduce or eliminate savings. Savings from fuel cell operations will continue to be impacted by market prices of natural gas and electricity, both in the short run and over the long run. Current natural gas costs are extremely high, by historical standards, and most forecasts show a moderation of gas prices over time. If this prediction is accurate, the savings produced by fuel cell operation will improve.

5.4 Thermal Production

In addition to electricity, the fuel cell has a heat recovery system that uses waste heat in the exhaust to heat water for the Barracks' galley. The heat recovery boiler was designed to produce 431,000 Btu per hour with the fuel cell operating at full capacity. Instrumentation was installed to measure the flow rate of the water in the secondary loop and both the supply and return water temperature. From this information, the Btu's delivered can be calculated. Unfortunately, this information was not collected and stored with the hourly data used for this report. Therefore, the thermal energy delivered was calculated using an 85 percent utilization factor. The calculations were validated with spot checks of the Btu meter. The design thermal performance expectations for the DFC300 are outlined in Table 13. A synopsis of the key performance results is included in Table 14.

Table 13. Thermal Design Performance Expectations.

Net Efficiency at Rated Output	45% LHV
Fuel Consumption at Rated Output	32 SCFM @ 933 Btu/cf LHV
Available Heat at Rated Power	Approx. 431,000 Btu/h
Heat Exchanger Maximum Exchange Rate	Approx. 431,000 Btu/h

Table 14. Actual Thermal Performance (June 1, 2003-May 31, 2004).

Total Fuel Consumption	109,480 ccf	
Net Thermal Delivered	1,832,076 mmBtu	
Input Energy	10,181,649 mmBtu	
Maximum Recoverable Heat from Exchanger	3,641,519 mmBtu	8449 Operating Hours
Capacity Factor	0.50	Delivered/Maximum Recoverable

Determining the actual performance of thermal loads has been difficult to date. Fuel bills, although providing a means of validating consumption from year to year, vary widely at Air Station Cape Cod. This is due to significant changes in population within the barracks and at the Base in general. . This increase in population impacts hot water consumption due to the variation in the number of meals prepared in the galley and the number of showers taken.

Although a Btu meter to monitor actual Btu recovered by the Heat Recovery Unit was included within the original project installation, the wrong meter was procured and there was a delay in receiving the correct meter. The Btu meter has recently been installed, which will enable accurate determination of these values for future reports.

Based on expected and actual electrical performance, one can determine the maximum heat that can be obtained from the exhaust via the heat recovery unit. From the initial feasibility study, it was determined that kitchen/DHW loads would utilize approximately 31.5 percent of the total exhaust heat load. Using a 75 percent boiler efficiency rate, the kitchen loads can in turn be converted to natural gas and cost savings.

Cost savings generated through thermal recovery can be directly applied to total cost savings. The thermal energy reclaimed directly relates to natural gas that does not need to be purchased and thus reduces the total operating costs for the system.

Unfortunately, without the benefit of a functional Btu meter during the data collection period and a more complete record of natural gas bills since the fuel cell has commenced operating, these figures remain highly suspect and should not be considered reliable. With the Btu meter now installed, a more complete thermal analysis will be undertaken in the future.

5.5 Overall Efficiency

For the evaluation year, the fuel cell delivered 1,832,076 million Btu's to ASCC's water system. The fuel cell delivered 1,250,174 kWh's of electricity. The total energy delivered was 6,098,919 million Btu's. The natural gas fuel utilized by the system had an initial energy content of 10,181,640 million Btu's. Therefore, the total system efficiency was 59.9 percent. The breakdown between thermal and electrical efficiency are approximately 18 percent and 42 percent, respectively. Table 15 provides complete monthly energy delivery and efficiency results.

Table 15. Monthly & Overall Energy Delivery & Efficiency.

Month	Net Electricity Delivered (mmBTU)	Net Thermal Delivered (mmBTU)	Total Energy Output (mmBTU)	Gas Used (ccf)	Input Energy (mmBTU)	Overall Efficiency
June-03	94734	138822.47	462149.612	9670	899310	51.4%
July-03	109255	160102.28	532989.595	11010	1023930	52.1%
August-03	110833	162488.39	540761.419	7000	651000	83.1%
September-03	103531	151713.74	505065.043	9970	927210	54.5%
October-03	113127	165776.6	551879.051	9360	870480	63.4%
November-03	102293	149899.87	499025.879	7980	742140	67.2%
December-03	111454	163324.11	543716.612	10340	961620	56.5%
January-04	110354	161712.02	538350.222	8640	803520	67.0%
February-04	97655	143104.08	476400.595	8670	806310	59.1%
March-04	98693	144624.87	481464.079	8360	777480	61.9%
April-04	84433	123727.83	411897.659	9060	842580	48.9%
May-04	113812	166779.52	555219.876	9420	876060	63.4%
Totals	1250174	1832075.78	6098919.642	109480	10181640	59.9%

6 FINANCIAL ANALYSIS

Determining whether fuel cells could provide less expensive power to Coast Guard facilities was one of the primary purposes of this research and development effort. Although much of the capital cost of the project was defrayed by grants, the complete costs of operations and maintenance (O&M) for the system are being borne by USCG funding. Initial project life cycle estimates that used expected costs for commercial electricity, natural gas, and system maintenance projected the fuel cell savings would adequately cover the annual O&M, the cost to restack the fuel cell at a five year interval, and provide a modest surplus savings to help defray the capital investment. A synopsis of costs and savings for the first year are provided in Table 16.

Table 16. Cost & Savings Comparison.

Description	Units	$/per unit	Annual $
Electricity Delivered by Fuel Cell (kWh)	1250174	0.1129	141,145
Thermal Delivered by Fuel Cell (ccf)	26266.3	1.11	29,156
Deferred Costs (Savings)			170,300
Natural Gas for Fuel Cell (ccf)	109480	1.11	121,523
Operations & Maintenance			24,913
Costs			146,435
Net Savings			23,865

The deferred costs or "savings" of the fuel cell falls into two categories. First, the electricity produced by the fuel cell reduces the amount of electricity purchased from the utility. The resulting savings are valued at the average purchase cost of the electric utility service during the period, which was 11.29 cents per kWh. The value of the thermal output from the fuel cell was calculated by converting the thermal delivery in Btu to the equivalent amount of natural gas. Using a boiler efficiency of 75 percent, the delivered natural gas can be found from the delivered Btu's, which in turn can be adjusted to determine the input volume of natural gas. The savings are valued at the average purchase cost of the natural gas for the period, which was $1.11 per ccf. The same value was used for the cost of fuel for the fuel cell. All maintenance expenses for year one were covered via the Design and Installation contract.

Deferred costs during the first year exceeded O&M costs resulting in a net savings of nearly $24,000. This savings was achieved despite the lower operating set point and the very high price of natural gas during the period. The project plan projected first year savings of $50,000, or two times the actual results.

Although the first year's maintenance was covered by the initial design and installation cost, no mechanism was put into place at the outset of the project to deal with maintenance for future years. Since this fuel cell is one of the first of its kind installed by FCE, specific maintenance plans, programs, and costs were not available at the time of the initial contract. As previously stated, it was believed the total savings generated by the fuel cell would exceed the costs of operating, maintaining, and repairing it. Unfortunately, this has proven to be a false assumption.

Recognizing the complexity of the fuel cell far surpassed the ability of the ASCC or any other USCG facility engineering shop to maintain it, the RDC submitted a Request for Proposal to FCE for a comprehensive maintenance contract. The level of service requested in the contract was equivalent to that procured in the initial contract. In short, the ASCC staff would be responsible for completing a monthly single page checklist of simple items, such as checking salt levels in the softener and swapping out dirty air filters. FCE would manage the remainder of the maintenance, which also included responsibility for the heat exchanger and the interconnection equipment. The contract was developed with a one-year base year and four option years. The long-term maintenance contract was just recently awarded and went into effect on October 1, 2004. The cost for the first year is approximately $79,600 with subsequent option years' prices increasing five percent annually to approximately $96,700 in the fourth option year. Unfortunately, the original project plans utilized an estimated annual maintenance cost ranging from $25,000 to $45,000.

In addition to basic maintenance, the extended maintenance contract included a line item option each year to replace the fuel cell's stack if necessary. The most significant regularly scheduled maintenance item is the charge to replace the fuel cell stack. The original fuel cell stack is expected to have a life span of three to five years. Subsequent stacks are expected to have a life span of five to seven years. Due to the modular construction of the DFC 300A, the actual restacking process consists predominantly of swapping out the old stack with the new stack and conducting the necessary start-up testing and monitoring required for a new stack. The actual change-out process should take very little time thus minimizing system downtime and lost production. FCE's proposal for stack replacement ranged from $250,000 in year one to $304,000 in year five. The original project plans utilized an estimated restacking cost of $250,000, but projected the cost to decline in the future as the technology improves.

Without even addressing whether capital costs could ever be recovered, as becomes readily apparent when comparing the maintenance costs of upcoming years with the performance data of the recent year, the fuel cell becomes significantly more expensive to own and operate over the next several years. Costs easily surpass the minimal amount of projected savings. In order for this fuel cell to be cost effective, a number of events must occur. First, the fuel cell must operate at or near output capacity with maximum online availability thereby maximizing both the amount of electricity generated and recoverable heat. Second, the relative cost differential between commercial electricity and natural gas needs to widen substantially so that the cost to generate electricity with the fuel cell becomes much less expensive than commercial electricity. Finally, the stack life must be extended and the restacking fees must decrease in price in the future. As the data currently show, without significant improvements and cost reductions, the fuel cell will not be cost effective.

7 FUTURE WORK

Although installation is complete and the fuel cell is operating reliably, a number of issues and future work remain to be completed. Undoubtedly, the most important tasks to be completed are those that reduce total system costs and allow the DFC300A to operate at its design capacity. These tasks include replacing the current interconnection system with a system that enables export of excess power, maximizing recovery of all available heat from the exhaust stream for utilization in the adjacent barracks, and brokering of available renewable energy certificates. Additional work may also include the further study and possible installation of an energy management system for the base and the transfer/sale of excess power to other government agencies to assist them in their “green power” efforts.

7.1 Upgrade the Interconnection System – Currently Ongoing

As indicated on numerous occasions throughout this report, the most pressing, current issue is the inability to export excess power. Regardless of the cause(s) behind the unexpected lower loads, the first step towards maximizing the payback potential of the fuel cell is to run the system at continuous full load.

In order to export power, two steps need be undertaken. The primary hurdle to overcome is the drafting and actual execution of an export agreement with the commercial utility. As previously addressed, nearly a year elapsed between the time NSTAR was first contacted and a final agreement and approval was in place. Portions of these delays were attributable to the USCG’s contractor’s activity and the overall delay of the project. However, the remaining delays were incurred awaiting the response from the utility. As a result, the associated contract parties are concerned about implementing a timely and beneficial export agreement in the future.

The second, but easier step is to upgrade the interconnection technology such that safe, reliably metered power can be exported. Without a doubt, no export will occur without appropriate safeguards in place to protect both the USCG’s and commercial utility’s equipment and personnel

However, the fuel cell partners believe the utility will not find cause to disapprove an export agreement. Fortunately, the amount of power available to be exported from the fuel cell operating at full load is estimated to be small, approximately 52 MWh during an entire year (or about two percent of the fuel cell’s total possible production), and no more than approximately 100 kW at any given moment. Given such a small amount, it is more critical from an overall cost standpoint to run at full load than to recoup an equitable sale price from the utility for the excess power, although certainly equivalent credits or net metering would be preferable. Unlike some other installations NSTAR is currently engaged with negotiating, the ASCC fuel cell is never going to provide all the power to the base. Current estimates indicate nearly 35 percent of the total electricity used by the base will be procured commercially. When the remainder of non-operational electricity usage at ASCC is factored into the total USCG electricity usage at the Massachusetts Military Reservation, the fuel cell covers a very minimal amount of the total consumption (only a few percent). ASCC will always remain a relatively large NSTAR customer on Cape Cod. Finally, there have been concerns voiced to NSTAR by other Federal agencies about the inability to procure "green power" in accordance with their respective governmental mandates. The "green power" the USCG exports to the grid could in turn, be sold by NSTAR, possibly at a premium, to others seeking green power.

7.2 Maximize Thermal Recovery and Utilization

The HRU is currently only recovering a portion of the available exhaust heat energy. The current limitation is based upon the hot water piping system arrangement within the barracks. Rerouting the piping and changes to existing boilers will need to be completed. However, currently funding is not available. A civil engineering project request for this work has been submitted for consideration to appropriate USCG authorities. Completion of this work is estimated to raise the total system efficiency an additional five percent.

7.3 Broker Renewable Energy Certificates

Renewable Energy Credits (RECs) are a newer addition to the green energy market. These credits may be sold to other parties according to appropriate state laws. This new source of revenue may help to offset annual maintenance or other project costs, thus improving the economic viability of the project. Regardless of how they may be used or sold, RECs or any other form of renewable energy grants/fees should be thoroughly researched at the project's outset and included as appropriate. The Coast Guard is currently discussing with FCE, Inc. an agreement to exchange or sell RECs to FCE, Inc. as a means of reducing the annual O&M costs. If this solution is impractical, the Coast Guard will entertain other means for selling/exchanging the RECs.

One additional area the USCG needs to pursue regarding the fuel cell is the sale of renewable energy certificates (RECs). A number of government laws and programs fund or allow for the purchase of power from environmentally preferred power sources. These purchases are in the form of RECs. Electricity RECs are typically based upon a cost per kWh or MWh produced. Recently in Connecticut, REC prices ranged from $20 to $30 per MWh.

For the ASCC fuel cell, the ramifications of selling the RECs are significant. For example, given an operational availability of 90 percent and 250 kW capacity, the fuel cell produces 1971 MWh per annum. At an average cost of $25/MWh, the RECs would net nearly $49,000 per year. At current estimates for annual maintenance of $79,600, the income from the RECs could offset a significant portion of the maintenance costs.

7.4 Contract Natural Gas Prices

The ASCC does not currently have a delivery contract in place for its natural gas consumption. As a result, it continues to pay at basic consumer rates. At full capacity and 90 percent operational availability, the fuel cell is estimated to consume approximately 150,000 ccf of natural gas per year. Given this consistent, predictable, and continuous gas consumption rate, it would benefit ASCC to negotiate a lower gas rate for the fuel cell gas account, if not all gas accounts. Given previous operating cost figures, even a few cents less per CCF would result in significant savings.

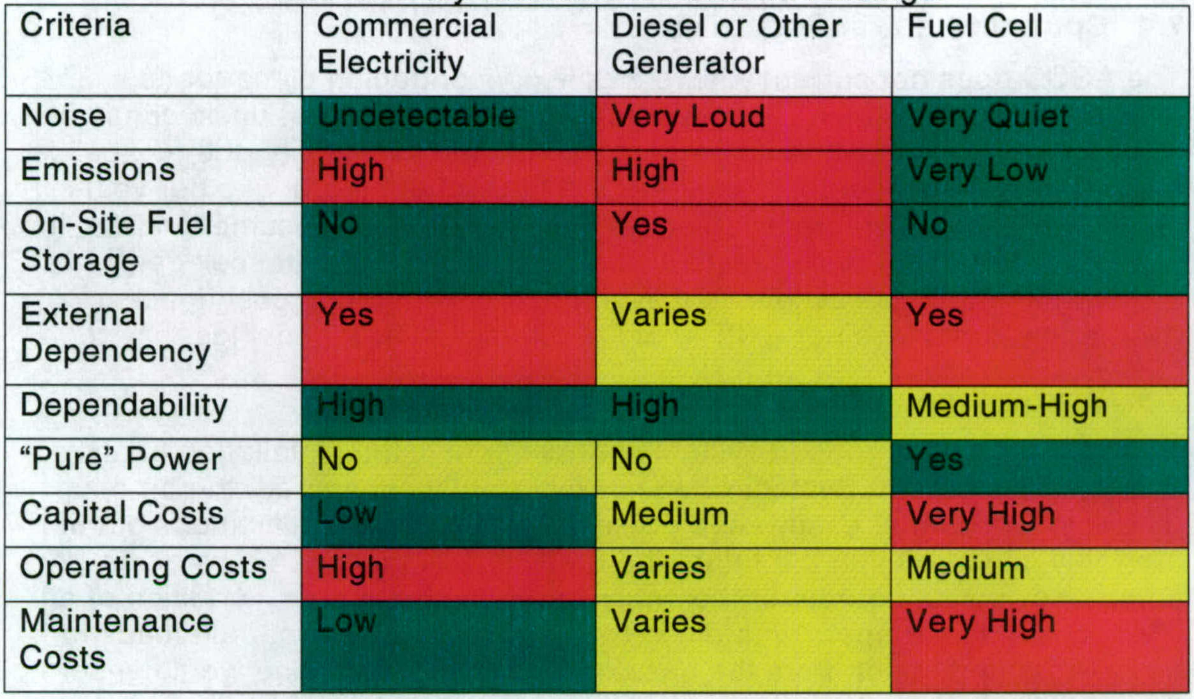
7.5 Energy Management System

A final, long term proposed system improvement is the installation of an Energy Management System (EMS). As currently configured, the on-base utility system cannot easily shed or isolate loads. The ramifications of this are fairly important if in the future the fuel cell was going to serve as an emergency power source for the entire operating base area. Addition of an EMS, estimated at approximately $250,000, would enable certain loads to be isolated and cut off from the base grid. By doing this, one would ensure that only the most critical loads are being carried by the fuel cell at any given time.

8 FINDINGS AND RECOMMENDATIONS REGARDING CG SHORE FACILITY FUEL CELL APPLICATIONS

The power options, which are or could be applied at ASCC, are compared with the project's key performance criteria in Table 17. Items colored green are good or positive attributes, yellow are neutral, and red are considered bad or negative attributes.

Table 17. Key Performance Criteria Findings.



Criteria	Commercial Electricity	Diesel or Other Generator	Fuel Cell
Noise	Undetectable	Very Loud	Very Quiet
Emissions	High	High	Very Low
On-Site Fuel Storage	No	Yes	No
External Dependency	Yes	Varies	Yes
Dependability	High	High	Medium-High
"Pure" Power	No	No	Yes
Capital Costs	Low	Medium	Very High
Operating Costs	High	Varies	Medium
Maintenance Costs	Low	Varies	Very High

As has been discussed, the fuel cell is an excellent choice when noise, emissions, and power quality are primary drivers. However, currently, the fuel cell is not as reliable as other power options. Also, and most significantly, the fuel cell is not cost effective in regards to its high capital and maintenance costs. Although, its operational costs are lower than the other options, the added costs of maintenance quickly and easily drain operating savings.

Although costs were only one criterion being considered, the current total costs for fuel cells, including capital, operating, and maintenance costs, are substantially greater than anticipated or so much higher than other power sources, that cost considerations overrule other criteria. Using cost alone, fuel cells are not recommended for other CG shore facilities at this time. However, as the technology improves, fuel cell costs are expected to decrease. Therefore, fuel cell technology costs should continue to be monitored. Possibly, there will be a time in the future when fuel cells will be practical for installation at other CG sites.

9 CONCLUSIONS

9.1 Operational Availability

The fuel cell operated with mixed success during its first year of operation. From an availability standpoint, its 96.2 percent operational availability exceeded its 95 percent expected value.

There were eighteen shutdowns during the year ranging in duration from a few minutes to several days. The most significant shutdown, to replace the carbon desulfurizer, was indicative of learning about operating new technology in actual field conditions.

9.2 Electrical Performance

Regarding actual electrical production, the overall capacity factor was only 0.569 vice an expected capacity of 0.90. The disparity between actual and expected was predominantly the result of the ongoing interconnection difficulties with the local utility. Design and negotiations are currently underway to significantly reduce or remove the restrictions.

Island Mode operation of the fuel cell proved the technology was a reliable source of grid independent power. Particularly noteworthy, the fuel cell served as primary power for 66 hours while the ASCC waited for Hurricane Irene to pass.

9.3 Thermal Performance

Recovery of the exhaust heat from the fuel cell to heat galley water reduced the barracks' natural gas consumption by approximately 26,300 ccf.

9.4 Overall Efficiency

The total system efficiency was determined to be nearly 60 percent. Thermal efficiency was 18 percent and electrical efficiency was 42 percent. Operating at design capacity will result in significant improvements to overall system efficiency.

9.5 Financial Results

Utilizing the fuel cell during the past year resulted in total cost savings of $23,865. Additional cost savings can be realized by operating the fuel cell at full capacity. The two most significant cost impacts on fuel cell operation are the price of natural gas and the cost of annual maintenance. As the relative cost differential between natural gas and commercial electricity widens, the fuel cell becomes economically more practical. Capital costs for fuel cells can be twenty times greater than other sources. Annual maintenance costs and restacking costs are much greater than originally anticipated. Given the fuel cell's production levels and the costs of natural gas and commercial electricity, maintenance costs negate all other savings. From a financial perspective, fuel cells currently are not a cost-effective technology solution.

9.6 Lessons Learned

Of the many lessons learned during this project, there are four noteworthy items that should be repeated. These particular items had, and continue to have, the greatest impact on this project.

- Extensive electrical utility engagement in any interconnection project is critical.
- Completeness and accuracy of data on which the project is based is mandatory (electric and thermal loads, operation and maintenance costs, avoided costs, interconnection, infrastructure changes, etc.).
- New technologies and their manufacturers and contractors will require flexible delivery and project schedules to allow for unforeseen complications and delays.
- The most significant challenge to fuel cell operation is the current rapid rise in natural gas costs versus the more slowly rising costs of commercially procured electricity. The cost differential between fuel cell produced electricity and commercially produced electricity is commonly known as the "spark gap." When this project was in its initial planning stages, natural gas cost approximately \$0.83 per ccf. During the first year's operation, gas cost an average of \$1.10 per ccf. In comparison, commercial electricity cost approximately \$0.103 per kWh at project inception and an average of \$0.113 per kWh during the first year's operation. Thus, during the lifetime of the project, the cost of natural gas has risen 33 percent compared to a more modest 9.7 percent increase in electricity costs. As the "spark gap" closes, the cost effectiveness of the fuel cell diminishes. Certainly, at current prices and given the current "spark gap" cost differential, capital cost recovery is impossible, and the annual O&M costs of operating a fuel cell become nearly equivalent to purchasing power from the commercial utility. If the cost differential were to invert, and commercial electricity were to be more cost effective than fuel cell produced electricity, the additional benefits of the fuel cell such as reliability, reduced emissions, clean power, and grid independence would have to be considered to determine if ongoing operation of the fuel cell was appropriate. Unfortunately, the costs of gas and commercial electricity are difficult to forecast and consumers have minimal ability to impact costs. Currently, the sole means of

impacting gas costs is via contract negotiations with the gas provider. The ASCC's gas contracts are negotiated via the General Services Administration (GSA), and the price is based on total consumption at the base. When the contract is due for renegotiation, the USCG will ask GSA to attempt to obtain a lower gas rate. Unfortunately, when compared to overall gas consumption on the complete Air Station, the fuel cell adds a relatively modest amount to the total usage.

- Lastly, as with any substantial project, planning, teamwork and communication are vital to the project's success.

9.7 Findings and Recommendations

Fuel Cells are not currently ready for distribution CG-wide. The technology is not cost effective on an annual basis and the capital costs are currently so high as to never be recouped even if annual operations produced modest savings. The reliability of fuel cells, although good, is not as good as the other existing commercial or emergency systems. However, the fuel cells are environmentally cleaner, quieter, and the power is high quality. Unfortunately, those benefits are secondary to cost and reliability at present. The CG should continue to monitor changes in costs and the reliability of fuel cell technology and specific products. With sufficient improvements, fuel cells may eventually become standard shore facility power providers.

APPENDIX A – Project Chronology and Schedule Impacts

As evident by the difference between the scheduled and actual performance dates, the project was completed one year behind schedule. These delays resulted from a variety of causes. Some impacts could have been better planned for or mitigated, others were the result of the risk and uncertainty associated with new technology, and a portion were both unexpected and uncontrollable. A chronological description of each schedule impact follows.

October 2001– Contract kick-off meeting held at ASCC. Because fuel cell production is behind schedule and winter weather rapidly approaching, the USCG agrees to PPL proposal to hold off all site work until next spring. A modification is made to the contract and the project schedule is revised to reflect this change.

December 2001 - Design work by PPL delayed one month. The delay resulted from the need to make basic changes to the plans and working with NSTAR and the CG to resolve interconnection issues. Additional design review time was allotted to allow for the drawings and specification to be sent to CG Civil Engineering Unit Providence for review.

January 2002 – Several events occurred in January that would result in significant delays to the project. Most importantly, an explosion occurred at FuelCell Energy's plant in Torrington, CT. Some workers were injured and a tape-casting machine that makes parts for fuel cell stack assemblies was damaged. Second, PPL's original design for handling of the fuel cell wastewater was not accepted by the CG CEU. All milestone dates were slipped one month to reflect the design challenges still remaining and the uncertainty of the impact from the explosion at the FuelCell Energy plant. The new dates were deemed simply a more realistic estimate, as it was believed unlikely that the fuel cell installation would meet the original schedule.

February 2002 - PPL met with the FuelCell Energy (FCE) management team to review the fuel cell production schedule and the impact from the explosion in January. FCE cannot provide a firm delivery schedule until their tape casting operation is fully restored, but they did state that delivery would not occur before June 1, 2002. Several design changes are still necessary to manage the wastewater stream. Project dates slip an additional two weeks.

March 2002 – FCE, Inc. indicates the plant damage will prohibit delivery of the fuel cell prior to late summer. A new contract schedule is received from PPL that shows a fuel cell delivery date of Aug 28, 2002. The final design meeting is held, final comments provided, and wastewater management plan approved. Final design submission deadline extended until middle of April 2002.

April 2002 PPL provides the R&D Center an updated fuel cell delivery date of 20 Sep 2002. Delivery date extended due to continued fuel cell manufacturing delays associated with repairs to damaged machinery. Schedule slips to accommodate. Site work is commenced.

May through July 2002 – Schedule remains unchanged. Site work is completed. PPL & NSTAR continue dialogue regarding the interconnection.

August 2002 – Results obtained during early phase of shop testing resulted in the minor re-design of stack elements. Delivery of fuel cell slips six weeks to account for redesign, re-engineer, and restart testing. During August, PPL completes and forwards engineering documents to NSTAR for approval.

September 2002 - Testing of the Fuel Cell continued during September. Unfortunately, the results of several tests conducted at the end of the month were outside of expected parameters. Most importantly, the stack was unable to meet the specifications requirement for an output of 250 kW. An analysis of the cause of the lower than expected power prompted minor design revisions to the stack module. The schedule slips six weeks to account for the changes.

October 2002 – Schedule remained unchanged. NSTAR provided requirements for connection of the fuel cell with the grid. PPL developed several potential options for meeting the NSTAR requirements and arranged to meet NSTAR staff in early November to select the appropriate installation option.

November 2002 – The fuel cell delivery was slipped by two weeks to early January to allow for highway shipping restrictions during the holiday season and to take into account staff impacts during the holidays.

December 2002 - PPL and NSTAR reached an agreement to enable interconnection of the fuel cell via a reverse power relay. The reverse power relay controls the fuel cell output and prevents power export from the fuel cell to the grid when the grid is offline. This stipulation was required for the safety of NSTAR equipment and personnel. Preliminary testing of the fuel cell was completed. The fuel cell did not perform as anticipated, prompting an in-house design review. The delivery date was slipped six weeks.

January 2003-May 2003 – A total of three additional weeks' delays accumulated during the five month period. These delays typically occurred in one or two-day increments associated with actual delivery date, installation, starting and completion of testing.

The January explosion that disabled the manufacturing plant for several months caused the most significant delays. This event was unforeseen and accounted for approximately sixteen weeks of delays. The remaining delays were basically the result of testing and re-engineering associated with the new technology.

Noteworthy for future projects were the delays hidden throughout the project that were masked by the manufacturing and testing delays. Significantly, the time required to obtain a final set of approved design documents was four months longer than anticipated. Even if the manufacturing had been completed on schedule, the project would have been delayed at least three months awaiting completion of the design and site work.

Finally, a year elapsed between the first meeting with NSTAR and their approval of an appropriate interconnection system. This process at first was believed to be easy and quick to complete. Obviously, the other delays resulted in less pressure being placed on completing the interconnection agreement. However, in future projects, this effort should be aggressively addressed and completed to avoid delays and unbudgeted project costs.

APPENDIX B – Lessons Learned

Possibly, the greatest value this fuel cell project will serve is to provide guidance and lessons learned for others investigating using this technology. Originally started as a Research & Development effort, the Coast Guard recognized the need to pursue and analyze the effectiveness of fuel cell technology. Because of the early stage of fuel cell commercialization, there are few people and organizations that have experience with projects of this type. As such, contracts completed and subsidized by government agencies and private corporations such as this are crucial to the ongoing development of new technology.

The lessons learned from this project are numerous. This fuel cell installation project was complex and unique for a number of reasons, such as dealing with new technology, identifying multiple funding sources, changes in personnel and schedules, etc. Most importantly, the project's success was dependent upon the effective and collaborative effort of a diverse group of partners with their own competing priorities, plans, and procedures. The following is an extensive list of lessons learned during this project including recommendations for future fuel cell installation endeavors.

Pre-planning Stage

a) Prior to commencing a project of this type and magnitude, all key decision makers need to be involved in the process of determining logical and productive sites that can best use all the energy that will be created. Artificially imposed criteria, such as convenient site location, can put inappropriate constraints on a project, which in turn may limit the ultimate feasibility for a given project.

b) Even within government agencies there are different sources of funding available to fund alternative energy projects. Funding should be sought out at all levels from the local unit to Headquarters, and from different offices and funds managers at each level (i.e. energy funds, environmental funds, shore facility management, and others). Ensure the funds managers understand present and future costs and the likelihood that costs will change.

c) A complete feasibility study should be conducted to uncover all technical and economic issues before commencement of a project of this nature. As part of this investigation, thoroughly examine all capital and life-cycle costs related to the project. Unfortunately, maintenance and outyear expenditures frequently are not appropriately estimated and analyzed because their values are not fully known. Keep in mind all the potential players, training, servicing, maintenance agreements, stack or parts replacement in out years.

Recommendations:

a) The project budget and contract should include the first two years' maintenance and repair costs. With regards to this project, it was assumed cost savings would be sufficient to cover future O&M costs. Although this may be true, it will likely take one to two years of data gathering and cost analysis to determine the actual costs and savings for the project and to have the appropriate funds reprogrammed for these expenditures. In the interim, it may be difficult to ascertain an appropriate funding source or responsible party.

b) Encourage free and open discussion on all aspects of funding, location, users, and players whom are likely to be engaged. Remember that some players may have had some less-than-positive previous relationships but still need to be fully involved. (Keep the discussion positive and keep other issues separate). Specifically for this project, there had been some recent issues between the USCG and the utility partners regarding prior billing practices. These old issues were wholly unrelated to this project, but could have damaged the working relationship needed to ensure success.

Feasibility Activities:

The foundation of this project consists of several studies that analyzed such features as design feasibility, load requirements, and economic viability. In retrospect, it is apparent that portions of these studies are inaccurate. It is imperative that project participants ensure that studies are relevant, timely, sufficiently long in duration and provide all necessary information in order to make correct decisions.

a) The energy load profile study is inaccurate for the ASCC facility. During acceptance trials, the loads at the facility were significantly less than predicted by the 1998 study. Even during the summer months when air conditioning loads were expected to fully utilize the available fuel cell output plus additional commercial grid power, the actual loads have been far less than expected. Unfortunately, short-term studies of energy use may not provide accurate or complete information since the period being analyzed may not be of sufficient duration or indicative of true conditions.

b) Connecting new equipment to existing infrastructure (such as transformers, utility interconnections, piping) can be difficult since the existing may not fit well with the new equipment. This will impact project location, mobilization, construction, etc., all of whose costs must be accounted for in project budgeting, design, and scheduling. For example, a significant amount of cost and time was expended in trenching and installing new utility ducts and hot water piping to connect the fuel cell to the barracks and to the base utility grid. In general, the older the facility, the more intensive is the effort to connect new equipment to the existing equipment/facility. A fuel cell installation may be an ideal solution when planning for entirely new construction.

c) Perform an analysis or inspection of all equipment, lines, etc. adjoining or impacting the project. Although, it was known the main feeder conduit for the base is old and likely at the end of its service life, it was not considered an issue during design and construction. In retrospect there is conjecture the line may be the source of the loss of a significant number of kilowatt-hours. This situation may have resulted in higher than actual loads in the initial load studies.

d) Ensure an unbiased third party conducts feasibility studies. Ensure they understand all the associated project issues, technical and non-technical, prior to commencing work. The party performing the study must be knowledgeable in the type of energy system being installed, and should be provided with good data and accurate maps/drawings of the existing infrastructure/site. If complete data are not available at the outset, include provisions in the contract to have the information obtained as part of the study. Do not rely on estimated information. It is better to invest more money upfront in the initial studies than conducting revisions to plans and designs later. Make sure that the contract is well written and will get you the information you need in the form you need. Flawed or missing data resulting from an effort to save money upfront can result in significant additional costs later in the project. Specific additional information that was lacking from this project included a more complete record of utility usage, both electrical and natural gas, accurate statements of the costs of out-year maintenance, and a better understanding of the local utility's interconnection policies and procedures.

Project Team:

a) The ability for many costly energy projects to be funded will often depend on having partnerships with relevant agencies such as DoD, CERL, DOE and with your State energy agencies. It also may be important to form liaisons with local community groups. Keep in mind that "buy-in" is easier than trying to sell the project merits after the fact. ASCC feels exceptionally lucky to have a good working relationship with the local communities and elected representatives.

b) Ensure that the prime contractor and manufacturer have a good working relationship as it does play an important role in ensuring the success of the project. This project benefited from having the prime contractor, subcontractors and manufacturer all working together for project success. At a minimum, ensure frequent and open communications are maintained between all parties. Also, although good project management typically dictates the client deal solely through the prime contractor, this type of relationship proved unfeasible, and the subcontractors were frequently contacted directly. However, in these instances, it was always appropriate to advise the contractor of the discussions, or to invite the prime contractor to participate in the discussion.

c) Designate within the contract a standard minimum communications interval, such as a monthly teleconference, bi-weekly report, etc. The prime contractor's representative should be in contact with the government contractor as frequently as needed, but no less than every two weeks. Although there may be no significant progress to address, continuous contact is still important.

d) In retrospect, too much interaction occurred between Coast Guard personnel and FuelCell Energy, a project partner but legally a subcontractor. Specifically, the Coast Guard personnel should have forwarded issues through the Contracting Officer vice going directly to the prime or subcontractor. At a minimum, the Government project manager and the prime contractor's project manager need to be involved in or aware of all discussions.

e) Consistency of key personnel is critical for the success of any large multi-year and multi-partner endeavor since a significant amount of project history and "corporate knowledge" is lost whenever personnel change. Unfortunately, the USCG and other partners changed personnel on several occasions and at inopportune times. Unless entirely unavoidable, key personnel should remain with the project for its entire duration.

f) Ensure the contractors are prepared to support the project at both the front end and the tail end. For this project, the contractor is still developing its customer service and maintenance services. Obtaining answers to maintenance questions and other pertinent information was sometimes slow since the information did not yet exist or it was difficult to identify the responsible division or individual.

g) The various project partners and grantors all had more experience in projects of this nature than the USCG personnel, and were willing to assist and use their expertise. Prospective fuel cell purchasers who may not be entirely versed in electricity production should fully utilize the knowledge base of the other involved parties, particularly in regards to economic analysis, interconnection, and basic electricity generation and distribution.

Project Design and Operation Issues

a) When dealing with new technology, determine early in the project, which tasks are most important and then assume their schedules will inevitably slip. Recognize some may slip substantially. Ensure your project timeline contains reasonable flexibility to account for alterations. In most outdoor construction projects, the greatest culprit behind project delays is weather. An early or long, harsh winter or extremely wet spring could have added significant delays to the project schedule. Also, expect the unexpected. No one could have conceivably expected a fire at the fuel cell manufacturing facility would have occurred and caused such a lengthy delay.

b) One of the purposes of this project is to reduce maintenance costs and ultimately eliminate the need for emergency generators at the site. Although this goal may be obtainable once the fuel cell technology matures and proves itself reliable, it was inappropriate to believe the emergency generators would be removed expeditiously from the site. Although the fuel cell has been running reasonably reliably, there have still been a few occasions where the fuel cell tripped offline in conjunction with a commercial grid outage. Without the existing emergency generators, the facility would have been wholly without power. For new installations, owners/users should plan on maintaining and operating their existing infrastructure/redundant systems for a period of time commensurate to the maturity and reliability of the new system being installed.

c) Although an Energy Management System (EMS) capable of shedding or picking up loads was originally envisioned for the project, the cost of the system would have exceeded the project budget, and the requirement was subsequently removed from the contract. The impact of this has yet to be seen, however, given fuel cell technology is not currently conducive to load following, there is the potential for problems to arise due to rapidly changing loads and the inability for the fuel cell to compensate.

d) Change can be difficult, particularly when introducing new equipment, technology, procedures, etc. to existing staff at the host facility. Field changes to existing equipment and new electric and plumbing equipment must be clearly marked and easily identifiable. New drawings and operating information must be readily available, and personnel must be thoroughly trained on how to conduct maintenance and operations procedures.

e) Ensure all parties are thoroughly aware of the ancillary support needs for the equipment. In particular, phone lines/Internet connections are required to ensure the equipment can be monitored and controlled from remote locations. Although phone lines were available, a high speed Internet connection was not. At first this absence made controlling and monitoring the fuel cell difficult. Later it was determined a continuous Internet connection may not be entirely appropriate due to security and hacker concerns. Regardless, the process and requirements for remote monitoring were not entirely understood nor in place prior to the fuel cell's installation.

Utility Considerations:

a) The importance of engaging the local public utilities at the outset cannot be over-emphasized. The local electrical utility, NSTAR, was not appropriately approached early in process. As a result and as previously presented, the project incurred additional construction costs to install an appropriate anti-islanding relay to resolve the interconnection requirements.

b) Regarding NSTAR's participation, the partnership inappropriately assumed NSTAR would be a more willing and eager participant. Ultimately, NSTAR dealt with this project professionally and did absorb most of their internal costs associated with reviewing the interconnection proposal.

c) In addition, the interconnection solution chosen may have solved the short-term problem, but has already proven to be the incorrect long-term solution. As a result, we now have interconnection issues that will require expenditures of additional manpower and fiscal resources to resolve.

d) Keyspan, the natural gas provider, was a willing project participant at the outset who provided a $100K grant that covered the costs of connecting the fuel cell to the gas main. Although communications between Keyspan were typically very good, there were a few instances where schedules and requirements were not fully relayed or were incorrect. Fortunately, all parties' willingness to work together resulted in timely resolution of these issues.

e) Other utility suppliers must be considered when installing a fuel cell system. Water pressure, chemistry and consistency of service are important to fuel cell performance and operation. There have been issues with both pressure and quality. At one point, a booster pump had to be installed to resolve the pressure problems. Advanced monitoring of the water system in the initial study phase may have identified these potential problems, so they could have been resolved in the design/construction phases of the project.

Recommendations:

a) Ensure the utility company understands the intent of the connection and how it will be used. Ensure they understand and can cooperate in interconnection issues at the team and corporate level. Engaging at the field and design engineering level is good, but it cannot be over-emphasized that the utility management should be fully engaged and understand grid connection issues. It is likely the utility engineering staff will lose interest if the senior levels of management do not make the project a priority. Also, participation at the corporate level frequently results in more timely approval of proposals or resolutions of conflicts.

a) In cases where the utility does not appear to have the ability to reap immediate returns on the time and effort invested in a project, the project team needs to demonstrate to the utility the potential long-term benefits of their participation such as positive publicity or the potential to move into a new market. Conversely, the utility should understand there might be long-term costs and drawbacks associated with not participating in certain projects.

b) Costs for utility rates, connection fees, engineering fees and connection equipment required by the utility companies should be determined as early as possible in the process. Variations of these fees can result in significant cost fluctuations, which could ultimately change the economic analyses and cost-benefit determinations. Although interconnection with the grid was anticipated and programmed into the project costs, the need for additional, expensive anti-islanding equipment was not foreseen.

c) Ensure utility partners are aware of the various project time requirements and are engaged with the engineers and contractors so equipment is agreed to prior to the start of site work. Most transformers and switches have long-lead times and may need to be special ordered. A binding contract, even if it has no cost associated with it, which thoroughly defines performance and timeframe could be an appropriate mode for ensuring partners fulfill their responsibilities.

d) If the electrical utility offers interconnect engineering and/or construction services, utilization of their in-house expertise can serve both as a means of engaging them as partners and ensuring the most appropriate interconnection methodology is utilized for the given project.

Responsibility for all aspects of the interconnection of the fuel cell to the grid should be explicitly stated in the contract. This responsibility may include not only engineering and construction services, but also which party shall be responsible for dealing with the local commercial utility provider to ensure compliance, etc. Negotiate the natural gas rate when installing a fuel cell system. Given the fuel cell's high natural gas consumption, the USCG, working through appropriate federal government contract channels, should have negotiated with Keyspan Energy to obtain a less expensive gas rate. The local facility manager has been advised of this issue and intends to address the gas rate as well as the rate for other services at the base with the government's contracting officer at the next contract renewal.