Small Scale Fuel Cell Application Templates

Final Report

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Contract CM622

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Introduction

In January 2006, the Houston Advanced Research Center (HARC) started work on Small Scale Fuel Cell Application Templates project using funding from U.S. Environmental Protection Agency (EPA) and administered by the Texas State Energy Conservation Office (SECO) through contract # CM622.

Program Goals

The goal of this fuel cell template project is to produce ten (10) templates of generalized fuel cell applications. The fuel cells were restricted to polymer electrolyte membrane (PEM) type due to maturity of the technology at a smaller scale. The templates will be a tool that EPA can use to identify and describe interesting and promising ways that fuel cells can be deployed, thereby generating additional interest among organizations which fall under EPA's jurisdiction regarding implementation of additional fuel cell demonstration projects.

The purpose of these templates as described in the proposal is two fold. The templates give EPA a catalog of potential supplemental environmental projects (SEP). As funding becomes available, EPA will have a ready list of details on the deployment of small scale fuel cell applications and type of public and non-profit institutions who will generally be interested in partnering in such a project. The deployment of small-scale polymer electrolyte membrane fuel cells in these institutions will demonstrate the benefits of low emission fuel cells and accelerate the implementation of fuel cells throughout the region and the state. The purpose was to produce a application template which is more generic than specific, and can be implemented in a wide variety of settings based on the host site. These templates support the improvement of air quality though the use of fuel cells to reduce the NOx emissions from electricity and heat production in the EPA Region 6.

Accomplishments

In January 2006, after the project kick-off meeting, HARC and SECO brainstormed a range of potential residential, commercial, and industrial applications for fuel cells. HARC also got engaged in conversations with several institutions like Houston Zoo, Houston Arboretum, Ellington Field, etc. that are potential sites for these project applications. A total of ten (10) fuel cell applications were selected – based on the best overall mix of commercial viability, technology appropriateness, and environmental performance. HARC created these ten small fuel cell application templates. These templates contain important technical and logistical information that can support the decision making process for SEP participants.

The ten templates which were selected as a part of this project include:

1) Fuel cell based combined heat and power for a commercial green house
2) Fuel cell based forklift for materials handling industry
3) Fuel cell based back-up power systems for aquarium tanks
4) Fuel cell based combined heat and power for Houston Zoo

5) Fuel cell based combined heat and power application for car wash, laundry, and similar institutions
6) Fuel cell based emergency back-up power for police stations, fire stations, radio stations, and similar institutions
7) Fuel cell powered air tuggers for demonstrations at airports
8) Fuel cell based portable power generator for landscaping equipment
9) Fuel cell based emergency back-up power for 911 call processing centers
10) Fuel cell auxiliary power unit for heavy-duty diesel trucks

The detailed description including environmental overview, cost overview, and general cost-benefit analysis for each of these ten project topics are described in application templates attached in *Appendix A.*

Table 1 provides a synopsis for the ten templates in terms of cost benefits to the host and NOx savings on a yearly basis.

Conclusion

The Houston Advanced Research Center has successfully completed ten small scale fuel cell application templates. The Center has been delivering monthly progress reports to SECO as described in the contract. This final report provides a complete detailed description on all the ten templates.

Table 1: Cost benefit to host ($/year) and NOx savings (kg/year) on a yearly basis for ten fuel cell application templates.

S.No.	Title	Cost benefit to host ($/year)	NOx savings (kg/year)
1.	Fuel cell based combined heat and power for a commercial green house	(1,650)	40.1
2.	Fuel cell based forklift for materials handling industry	193	335.9
3.	Fuel cell based back-up power systems for aquarium tanks	210	8.1
4.	Fuel cell based combined heat and power for Houston Zoo	(2,000)	35.5
5.	Fuel cell based combined heat and power application for car wash, laundry, and similar institutions	(1,186)	22.8
6.	Fuel cell based emergency back-up power for police stations, fire stations, radio stations, and similar institutions	415	32.4
7.	Fuel cell powered air tuggers for demonstrations at airports	(15,035)	(11.1)
8.	Fuel cell based portable power generator for landscaping equipment	49	7.76
9.	Fuel cell based emergency back-up power for 911 call processing centers	60	32.4
10.	Fuel cell auxiliary power unit for heavy-duty diesel trucks	171	358.9

* Numbers in bracket indicates negative quantity

APPENDIX A

FUEL CELL APPLICATION TEMPLATES

SEP PROPOSAL

TEMPLATE # 1
EPA FUEL CELL APPLICATION

APPLICATION TITLE:	**FUEL CELL BASED COMBINED HEAT AND POWER FOR A COMMERCIAL GREEN HOUSE**
Type of Facility:	*Commercial greenhouse (and indoor aquaculture) or similar*
Purpose of fuel cell:	*Provide electric and thermal energy for green house*
Institutions interested in this application:	*Parks and universities with horticulture gardens*

APPLICATION OVERVIEW

Objective

The primary objective of this project is to reduce the toxic emissions related to the operation of natural gas or propane heaters (and in some cases coal and oil) for greenhouse heating in the EPA Region 6.

In Texas, solar energy represents a significant proportion in greenhouse heating. Irrespective of this, supplemental heating systems are required for year round protection. A grid-connected fuel cell will provide electricity year-round, and thermal energy on a need basis. This will help reduce the emissions with use of grid power and natural gas heater, and provide source of uninterrupted power supply.

Fuel Cell Description

Combined heat and power (CHP) applications involve the use of a fuel cell in a wide variety of small commercial or industrial applications. The fuel cell in this application would generally be an AC device that is interconnected with the grid, where thermal energy from the fuel cell is captured and used to offset the combustion of natural gas or electricity to produce hot water for domestic uses (bathroom, kitchen, etc.). By avoiding both utility electricity production and the combustion of natural gas for water heating, the fuel cell CHP application results in NOx savings. It also reduces CO2 emissions due to the overall efficiency of the system.

The technology under consideration is a 5 kW natural gas fueled polymer electrolyte membrane (PEM) fuel cell from Plug Power (http://www.plugpower.com). The system is commercially sold under the name GenSys, and is available for purchase from the manufacturer. At least one other manufacturer, Nuvera, has a similar configured product, and is sold under the brand name of Avanti. The fuel cell is designed for residential and small commercial applications. The system produces 120/240 VAC @ 60 Hz and can be connected to the electrical utility grid. The system can be installed for combined heat and power (CHP) capability and is intended to supply base-loaded electrical power and thermal energy to the greenhouse. The system can be set to able to

follow the load up to 5 kW maximum power rating. The CHP capability allows thermal energy produces by the fuel cell system to be used in the existing domestic hot water and space heating systems.

Equipment specifications from Plug Power and real world demonstrations suggest that the system has an electrical efficiency in upwards of 25% (when new). Test data from several demonstrations also suggest that the unit degrades by about 20% (5 percentage points) in about 8000 hours of operation. The system also produces 9 kWth of thermal energy. Recent claims from Plug Power and test data suggest that the fuel cell stack has a durability of around 8000 hours, although a deviation of ± 2000 hours is common. The system is CSA, UL, and FCC Class B certified.

Installation

Codes, Standards, and Permits
The Plug Power GenSys fuel cell system complies with the following standards:

- ANSI Z21.83, Fuel Cell Power Plants
- UL 1741, Inverters, Converters and Controllers for Use in Independent Power Systems
- NFPA 70, National Electrical Code
- Code of Federal Regulations 47, Part 15, Telecommunication Requirements
- IEEE P1547, Standard for Interconnected Distributed Resources with Electrical Power Systems
- New York State Standardized Interconnection Requirements
- California Energy Commission, Rule 21 Standard Interconnection Requirements

The implementation of distributed generation (DG) is subjected to interconnection rules, building codes, electric generator codes, emissions standards and other regulatory requirements, which vary from state-to-state. Individuals or organizations taking the installation are recommended to contact their local power utility company, local, and state regulatory authorities to discuss requirements to meet the prevailing codes, regulations, and interconnection permits.

Typical Installation Considerations
Installation considerations when choosing a site are normally detailed in the manufacturer installation manual. Listed below are the excerpts, and some real world considerations:

- Site selection should be achieved consistent with fuel cell technical specs, local building and fire codes. System must be placed in area of adequate ventilation and safety – four feet from walls, combustible/hazardous materials, etc.; and ten feet from walkways, trees, forced air building inlet, etc.; system must be accessible for vehicle access for installation and service, and for emergency personnel. Bollards and security fencing may be required.
- Interconnection agreement with the local electric utility should be started four months prior to expected system delivery. Also contact state/city/county regulatory agencies to understand permit requirements and obtain necessary permits

Typical Facilities Considerations
The fuel cell system is configured to run only with natural gas fuel. The fuel service should be established with the local gas company in advance of system delivery. The NG piping materials

and joining methods should be consistent with the national and local codes and regulations. The gas supply system should be constructed to the following requirements:

- Gas supply pressure range is 4-11 inches WC. A step-down pressure regulator is needed if the gas pressure exceeds this range. The gas line and meter should be capable of supplying a maximum demand of up to 100 cubic feet per hour.
- A regulator (if needed), drip and sediment trap, manual shut off valve, and union disconnect should be installed no more than three feet from the point of connection on the fuel cell enclosure to allow for future service and repair of equipment.
- A plugged, 1/4 inch NPT connection point for test gauge connection should be installed immediately upstream of the fuel gas supply connection to the fuel cell system.
- The gas line must be purged completely of air before operating the fuel cell system (large amounts of air are harmful to the fuel processor).

A standard municipal supply water connection (maximum required flow 75 cc/min at 5 kW) is required. The on-board water purification system generates DI water (3 and 18 MΩ) for use in the process. A five liter on-board water reservoir is integrated within the fuel cell system.

ENVIRONMENTAL OVERVIEW

Equipment:	*PlugPower GenSys™*
Time period of operation:	*1 year (continuous)*
Average power:	*5 kW*
Total electrical energy produced in one year:	*5 kW × 365 days/year × 24 hrs/day = 43,800 kWh = 43.8 MWh*
Total thermal energy produced in one year:	*9 kW × 365 days/year × 24 hrs/day = 78,840 kWh = 78.84 MWh*
Fuel:	*Natural Gas (delivered through pipeline – free of charge for Houston Zoo)*
Total Nat. Gas consumed:	*743 MCF (one year of operation)*

NOx savings

NOx emissions from fuel cell (~1.36 g NOx/MWh)	<<1 kg NOx/year
NOx emissions with use of grid power (0.5 kg NOx/MWh)	21.9 kg NOx/year
NOx emissions from NG heater (0.23 kg NOx/MWh)	18.2 kg NOx/year
Net NOx savings with use of fuel cell	***40.1 kg NOx/year***

CO2 savings

CO2 emissions from fuel cell (743 MCF NG)	41 tons CO2/year
CO2 emission with use of grid power (1.34 lbs CO2/kWh)	27 tons CO2/year
CO2 emissions from NG heater	19 tons CO2/year
Net CO2 savings with use of fuel cell	***5 tons CO2/year***

COST OVERVIEW

Equipment:	*PlugPower GenSys™*
Time period of operation:	*1 year (continuous)*
Average power:	*5 kW*
Total electrical energy produced in one year:	*5 kW × 365 days/year × 24 hrs/day = 43,800 kWh = 43.8 MWh*
Total thermal energy produced in one year:	*9 kW × 365 days/year × 24 hrs/day = 78,840 kWh = 78.84 MWh*
Fuel:	*Natural Gas (delivered through pipeline – free of charge for Houston Zoo)*
Total Nat. Gas consumed:	*743 MCF (one year of operation)*

Capital Costs	
Equipment (GenSys 5 kW)	$42,500
Shipping	$2,000
Installation	$15,000
Grid-interconnection	$5,000
Subtotal1	***$64,500***
O&M costs	
-based on 1 year of operation	
Maintenance Costs	$5,000
Natural Gas Costs ($8 per MCF)	$5,950
Subtotal2	***$10,950***
Total	**$75,450**

COST BENEFIT ANALYSIS FROM HOST PERSPECTIVE

-based on 1 year of operation of Plug Power GenSys at 5 kW power rating

Fuel cell expenses for electricity and heat	
Electrical energy produced from fuel cell	43.8 MWh
Thermal energy produced from fuel cell	78.8 MWh
Subotal1	***$5,950***
Fuel cell expenses for maintenance	
Subtotal2	***$5,000***
Current expenses for electricity and heat	
Cost of grid electricity (@$0.10/kWh)	$4,400
Cost of thermal energy ($8/MMBTU; 75% eff.)	$2,900
Subotal3	***$7,300***
Natural Gas heater maintenance	
Subtotal4	***$2,000***

Net Savings = *Subtotal3* + *Subtotal4* – *Subtotal1* – *Subtotal2*

Fuel cell net savings	**($1650)**

SEP PROPOSAL

TEMPLATE # 2
EPA FUEL CELL APPLICATION

APPLICATION TITLE:	**FUEL CELL BASED FORKLIFT FOR MATERIALS HANDLING INDUSTRY**
Type of Facility:	*Industrial warehouse, grocery stores or similar*
Purpose of fuel cell:	*Provide motive power to the forklifts for materials handling*
Institutions interested in this application:	*Grocery stores, Port of Houston, etc.*

APPLICATION OVERVIEW

Objective

The main goal of this project is to reduce the cost (capital, operational, and maintenance) and emissions related to the operation of diesel powered forklifts in the EPA Region 6. This can be achieved by the utilization of fuel cell powered forklift. Utilization of such forklifts also enables quiet and vibration free operation leading to improved ergonomics.

Fuel Cell Description

The technology under consideration is a 5 kW hydrogen fueled polymer electrolyte membrane (PEM) from Nuvera Fuel Cells (http://www.nuvera.com). The system is commercially sold under the name PowerFlow™, and is available for purchase from the manufacturer. At least three other manufacturers, Hydrogenics, Proton Motor, and Toyota have similar configured product are in different stages of development. The Nuvera Fuel Cell's system is designed to be installed into vehicles and equipment for a variety of applications, including material handling, airport ground support, turf care, construction and standby power. The system is capable of producing regulated 36 or 48 VDC which is fully compatible with the battery systems. The system can be set to able to follow the load up to 5 kW maximum power rating.

Equipment specifications from Nuvera and real demonstrations suggest that the system has an electrical efficiency in upwards of 50% (when new). The company's product is available commercially, although it is still evolving. Nuvera states that their PowerFlow™ systems have been tested for over 9000 hours without appreciable drop in performance. Test data from an earlier generation fuel cell system (H2e™) suggests the electrical efficiency to be 53% (when new) and dropping to 46% after 1800 hours of continuous operation. The system is not certified, and the company states that CE, CSA, and UL listing are underway.

System Integration and Operation

Fuel Cell Powered Forklift

There have been several fuel cell powered forklift demonstrations in the last 2-3 years. While the number of demonstrations continues to increase, manufacturers are still not willing to sell the products commercially due to the embryonic nature of the technology. On the good side, companies like Nuvera are working with East Penn Manufacturing Company to develop hybrid battery/fuel cell electric engines for forklifts. Most of the companies including Nuvera are developing products which can easily be integrated into the battery compartment of the battery powered electric forklift. Conversion of battery powered electric forklifts to fuel cell powered forklifts will thus need minimum resources in terms of efforts or cost. Such products are available for demonstration projects under limited terms and conditions.

Fueling Solutions

Fueling solutions for the fuel cell powered forklifts is not trivial unlike diesel powered forklifts. In most cases, the fueling solution to the customer is provided by the fuel cell manufacturer. The type of fueling solution is based on the fleet size of the forklifts and type of operation at a particular location. In most cases, onsite storage of compressed hydrogen is required for refueling purposes. Hydrogen can be generated onsite or delivered through trucks, and stored in high pressure tanks onsite (~5000 psi or so). In case of former, hydrogen is normally generated by steam reforming reaction in compact natural gas reformers. In some cases, electrolysis can also be used to generate hydrogen from water.

Nuvera Fuel Cells is developing a family of hydrogen generators called PowerTap™. This product is CSA and CE certifies. The PowerTap™ integrated system consists of a fuel processor assembly, a reformate compressor, a pressure swing absorption system, an electric-driven hydrogen compressor, and a dispenser. PowerTap™ product will serve as a fueling solution for the PowerFlow™ products – Nuvera's Total Power Solution™ (TPS) concept.

Nuvera Fuel Cells suggests that demonstration projects for the fuel cell powered forklifts will use hydrogen delivered onsite by trucks. PowerFlow™ products will eventually be available when the market demands for fuel cell powered forklifts increases or economics of the process demands the need. Consequently, this proposal will be based on hydrogen delivered through trucks and stored on-site in compressed form. On-site hydrogen compression and storage infrastructure will be developed (if not already available) and will be a part of this proposal.

Operation and Safety

The operation of the forklifts should be performed by certified and trained personnel only. The system should be operated as per the instructions in the operational and maintenance manual accompanying the product. Precautions common to battery powered forklifts should be followed during operation and refueling.

ENVIRONMENTAL OVERVIEW

Equipment:	*Nuvera Fuel Cells PowerFlow™ forklift*
Time period of operation:	*Five hours per shift, three shifts per day for 365 days per year (5475 hours)*
Average power:	*3.75 kW*
Total electrical energy consumed in one year:	*5 hours × 3 shifts × 365 days × 3.75 kW = 20.5 MWh*
Fuel:	*Hydrogen (delivered on-site by truck)*
Total Hydrogen consumed[1]:	1189 kg *(one year of operation)*

Case 1: Diesel powered forklift

NOx savings

NOx emissions from fuel cell forklift[2] (12.3 g/kg of H2)	14.6 kg NOx/year
NOx emissions from diesel forklift (17.1 kg/MWh)	350.5 kg NOx/year
Net NOx savings with use of fuel cell forklift	***335.9 kg NOx/year***

CO2 savings

CO2 emissions from fuel cell forklift (10.6 kg/kg of H2)	12.6 tons CO2/year
CO2 emissions from diesel forklift (824 kg/MWh)	16.9 tons CO2/year
Net CO2 savings with use of fuel cell forklift	***4.3 tons CO2/year***

Particulates savings

Particulates emissions from fuel cell forklift (2 g/kg of H2)	2.4 kg particulates/yr
Particulate emissions from diesel forklift (695 g/MWh)	14.2 kg particulates/yr
Net particulates savings with use of fuel cell forklift	***11.8 kg particul./yr***

Case 2: Propane powered forklift

NOx savings

NOx emissions from fuel cell forklift (12.3 g/kg of H2)	14.6 kg NOx/year
NOx emissions from propane forklift (23.8 g/kWh)	471.5 kg NOx/year
Net NOx savings with use of fuel cell forklift	***456.9 kg NOx/year***

CO2 savings

CO2 emissions from fuel cell forklift (10.6 kg/kg of H2)	12.6 tons CO2/year
CO2 emissions from propane forklift (1.1 kg/kWh)	22.5 tons CO2/year
Net CO2 savings with use of fuel cell forklift	***9.9 tons CO2/year***

Particulates savings

Particulates emissions from fuel cell forklift (2 g/kg of H2)	2.4 kg particulates/yr
Particulates emissions from propane forklift (67 g/MWh)	1.4 kg particulates/yr

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[1] Hydrogen flow is 60 slpm at 5.5 kW. System requires 58 grams of Hydrogen to produce 1 kWh electrical energy

[2] These (NOx, CO2, and Particulates) emissions are produced during hydrogen generation from steam reforming process in large central plants. So these refer to displaced emissions. Data taken from NREL report (NREL/TP-570-27637) "Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming."

Net particulates savings with use of fuel cell forklift	***(1 kg particulates/yr)***

Case 3: Battery powered forklift

NOx savings

NOx emissions from fuel cell forklift (12.3 g/kg of H2)	14.6 kg NOx/year
NOx emissions from battery powered forklift[3] (1.1 lbs NOx/MWh)	11.5 kg NOx/year
Net NOx savings with use of fuel cell forklift	***(3.1 kg NOx/year)***

CO2 savings

CO2 emissions from fuel cell forklift (10.6 kg/kg of H2)	12.6 tons CO2/year
CO2 emissions from battery powered forklift (1.34 lbs CO2/kWh)	27.5 tons CO2/year
Net CO2 savings with use of fuel cell forklift	***14.9 tons CO2/year***

Particulates savings

Particulates emissions from fuel cell forklift (2 g/kg of H2)	2.4 kg particulates/yr
Particulates emissions from battery powered forklift (80 kg/GWh)	1.6 kg particulates/yr
Net particulates savings with use of fuel cell forklift	***(0.8 kg particul./yr)***

COST OVERVIEW

Equipment:	*Nuvera Fuel Cells PowerFlow™ forklift*
Time period of operation:	*Five hours per shift, three shifts per day for 365 days per year*
Fuel:	*Hydrogen (delivered on-site by truck)*
Total Hydrogen consumed:	*1189 kg (one year of operation)*

Capital Costs

Fuel cell cost (5 kW PowerFlow™)	$18,000
Electric forklift (with batteries)	$15,500
Fuel cell integration into electric forklift	$2,000
On-site hydrogen compression and storage infrastructure	$4,000
Subtotal1	***$39,500***

O&M costs

Maintenance Costs	$500
Hydrogen Cost[4] ($7.5/kg)	$8,917
Subtotal2	***$9,417***

Total	**$48,917**

COST BENEFIT ANALYSIS FROM HOST PERSPECTIVE

[3] Emissions (NOx, CO2, and Particulates) are for the electrical grid that is used to charge the batteries

[4] Depends on region – can be between $5-10/kg. With on-site hydrogen generation this cost can be as low as $3/kg of hydrogen

Equipment:	*Nuvera Fuel Cells PowerFlow™ forklift*
Time period of operation:	*Five hours per shift, three shifts per day for 365 days per year*
Fuel:	*Hydrogen (delivered on-site by truck)*
Total Hydrogen consumed:	*1189 kg (one year of operation)*

Fuel cell powered forklift

Cost of hydrogen fuel (@ $7.5/kg of H2)	$8,917
Maintenance	$500
Subtotal1	***$9,417***

Diesel powered forklift

Cost of diesel (@ $0.42/kWh)	$8,610
Maintenance	$1000
Subtotal2	***$9,610***

Propane powered forklift

Cost of propane (@ $0.28/kWh)	$5,740
Maintenance	$1000
Subtotal3	***$6,740***

Battery powered forklift

Cost of grid electricity[5] (@ $0.10/kWh)	$2,278
Maintenance	$900
Subtotal4	***$3,178***

NET savings over diesel powered forklift = *Subtotal2 – Subtotal1 = $193/year*
NET savings over propane powered forklift = *Subtotal3 – Subtotal1 = (2,677/year)*
NET savings over battery powered forklift = *Subtotal4 – Subtotal1 = ($6239/year)*

[5] Assuming 90% charging efficiency

SEP PROPOSAL

TEMPLATE # 3
EPA FUEL CELL APPLICATION

APPLICATION TITLE:	**FUEL CELL BASED BACK-UP POWER SYSTEMS FOR AQUARIUM TANKS**
Type of Facility:	*Recreational parks with aquariums*
Purpose of fuel cell:	*Provide backup power for maintaining oxygen in fish water tanks*
Institutions interested in this application:	*Downtown Aquarium, Houston Zoo*

APPLICATION OVERVIEW

Objective

The primary objective of this project is to reduce toxic emissions and feature a clean energy generating technology, *i.e.,* fuel cells, at a public recreational park with aquarium. This will be achieved by application of a fuel cell backup power generator operating on pure hydrogen. The fuel cell generator will be used to run an air compressor during grid power failure, thereby maintaining required oxygen levels in the aquarium.

Fuel Cell Description

The technology under consideration is a 5 kW hydrogen fueled polymer electrolyte membrane (PEM) fuel cell from PlugPower (http://www.plugpower.com). The system is commercially sold under the brand name GenCore™, and is available for purchase from the manufacturer under standard terms and conditions. The cost of unit is around $15,000 ($3,000 per kW), but may vary based on the contract. At least three other manufacturers, ReliOn, APC/Hydrogenics, and Ballard have similar configured products, although these are available in different power ratings. The PlugPower GenCore™ is a commercial PEM fuel cell system specifically designed for back-up power applications for telecommunications equipment (like switching equipment, critical loads, etc.), but can be configured to be used for other backup power applications.

The UPS application appears to be particularly well-suited for PEM fuel cells like the GenCore™, because the application's low duty cycle requirement is consistent with the limited availability (i.e., high cost) of hydrogen fuel and with current stack durability limits of 1000 to 3000 hours. Plug Power provides a 1500 hour operating life warranty for the GenCore™ product, well above the run time expected during a 10-year life in a typical UPS application.

The GenCore™ 5T system is a 5 kW system with 48VDC output voltage. The unit runs on industrial grade 99.95% hydrogen and is designed for outdoor operations. Plug Power recently announced a 110 V system for use on the electric grid.

Application

The aquarium tanks need a reliably source of power to maintain a steady supply of air and circulation of fresh water. A diesel generator is normally used as back-up for the electric grid supply for this application. However, emissions of the diesel generator are much more compared to fuel cell generator (discussed in section of emissions savings). The fuel cell running on bottled hydrogen is much cleaner, maintenance free, is a reliable electric power generator, and can replace the existing diesel generator used for this application.

Installation

Codes and Standards
The PlugPower GenCore™ fuel cell system complies with the following standards:

- CGA 5.4, Standard for Hydrogen Piping Systems at Consumer Locations – PlugPower's fuel delivery system is designed and constructed in accordance with this standard
- CGA 5.5, Hydrogen Vent Systems – PlugPower's hydrogen pressure relief vent is designed and constructed in accordance with this standard
- NFPA 50A, Standard for Gaseous Hydrogen Systems at Consumer Sites, 1999 – Hydrogen gas supply system must be designed, constructed and sited in accordance with the requirements of this standard
- NFPA 70 National Electrical Code
- NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Plants, 2000 Edition
- ANSI Z21.83, Fuel Cell Power Plants – PlugPower's Fuel Cell System is designed in accordance with the requirements of this standard
- ICC International Fire Code – Table 2209, 3.1 Outdoor minimum separation distances for gaseous hydrogen dispensers, compressors, generators and storage vessels
- ICC international Fuel Gas Code – Chapter 7 – Gaseous hydrogen systems
- NFPA 497 – Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas

Typical Installation Considerations
Installation considerations when choosing a site are normally detailed in the manufacturer installation manual. Listed below are the excerpts, and some real world considerations:

- Site selection should be done consistent with fuel cell technical specs, local building and fire codes. System must be placed in area of adequate ventilation and safety – four feet from walls, combustible/hazardous materials, etc.; and ten feet from walkways, trees, forced air building inlet, etc.; system must be accessible for vehicle access for installation and service, and for emergency personnel. Bollards and security fencing may be required.

Typical Facilities Considerations
The fuel cell system is configured to run only with hydrogen stored in standard industry size T-bottles. The gas supply system should be constructed to the following requirements:

- Gas supply pressure range is 64-94 psig. A step-down pressure regulator is needed if the gas pressure exceeds this range.
- The gas line and meter should be capable of supplying a maximum demand of up to 75 slpm at 5 kW.
- A regulator (if needed), drip and sediment trap, manual shut off valve, and union disconnect should be installed no more than three feet from the point of connection on the fuel cell enclosure to allow for future service and repair of equipment.
- A plugged, 1/4 inch NPT connection point for test gauge connection should be installed immediately upstream of the fuel gas supply connection to the fuel cell system.
- The gas line must be purged completely of air before operating the fuel cell system

ENVIRONMENTAL OVERVIEW

Equipment:	*PlugPower GenCore™*
Time period of operation:	*Five years, providing backup grid security; 1000 operational hours*
Average power:	*2.5 kW (electrical)*
Total electrical energy consumed in five years:	2.5 MWh
Fuel:	*Hydrogen (delivered in standard industry size T-bottles)*
Total Hydrogen consumed[1]:	2.5×10^3 kWh × 0.08 kg/kWh = 168 kg *(five years of operation)*

NOx savings (five year basis)

NOx emissions from fuel cell UPS Generator[2] (12.3 g/kg of H2)	2.06 kg NOx
NOx emissions from diesel generator (17.1 kg/MWh)	42.75 kg NOx
Net NOx savings with use of fuel cell backup generator	***40.69 kg NOx***

CO_2 savings (five year basis)

CO_2 emissions from fuel cell UPS Generator (10.6 kg/kg of H2)	1.78 tons CO_2
CO_2 emissions from diesel generator (824 kg/MWh)	2.06 tons CO_2
Net CO_2 savings with use of fuel cell backup generator	***0.28 tons CO_2***

Particulates savings (five year basis)

Particulates emissions from fuel cell UPS Generator (2 g/kg of H2)	0.34 kg particulates

[1] Hydrogen flow is 63 slpm at 5 kW. System requires around 67 grams of Hydrogen to produce 1 kWh electrical energy

[2] These (NOx, CO2, and Particulates) emissions are produced during hydrogen generation from steam reforming process in large central plants. So these refer to displaced emissions. Data taken from NREL report (NREL/TP-570-27637) "Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming."

Particulate emissions from diesel generator (695 g/MWh)	1.74 kg particulates
Net particulates savings with use of fuel cell backup generator	***1.4 kg particulates***

COST OVERVIEW

Equipment:	*PlugPower GenCore™*
Time period of operation:	*Five years, providing backup grid security; 1000 operational hours*
Fuel:	*Hydrogen (delivered in standard industry size T-bottles)*
Total Hydrogen consumed:	*168 kg (five years of operation)*

Capital Costs	
Fuel cell cost (5 kW GenCore™)	$15,000
Shipping	$2,000
Installation	$4,000
Subtotal1	***$21,000***
O&M costs	
Maintenance Costs	$2,500
Hydrogen Cost[3] ($7.5/kg)	$1,500
Subtotal2	***$4,000***
Total	**$25,000**

COST BENEFIT ANALYSIS FROM HOST PERSPECTIVE

Equipment:	*PlugPower GenCore™*
Time period of operation:	*Five years, providing backup grid security; 1000 operational hours*
Fuel:	*Hydrogen (delivered in standard industry size T-bottles)*
Total Hydrogen consumed:	*168 kg (five years of operation)*

Fuel cell powered UPS Generator	
Cost of hydrogen fuel (@ $7.5/kg of H2)	$1,500
Maintenance	$2,500
Subtotal1	***$4,000***
Diesel powered UPS Generator	
Cost of diesel (@ $0.42/kWh)	$1,050

[3] Depends on region – can be between $5-10/kg. With on-site hydrogen generation this cost can be as low as $3/kg of hydrogen

Maintenance	$4,000
Subtotal2	***$5,050***

NET savings over diesel powered generator = *Subtotal2 – Subtotal1 = $1,050 (over 5 year period)*

SEP PROPOSAL

TEMPLATE # 4
EPA FUEL CELL APPLICATION

APPLICATION TITLE:	**FUEL CELL BASED COMBINED HEAT AND POWER FOR HOUSTON ZOO**
Type of Facility:	*Institutional*
Purpose of fuel cell:	*Provide electrical and thermal energy for the Zoo*
Institutions interested in this application:	*Recreational parks with Zoo, and similar places*

APPLICATION OVERVIEW

Objective

The primary objective of this project is to reduce the toxic emissions related to the operation of natural gas heaters and backup diesel generators in the EPA Region 6. This will be accomplished with the use of a grid-connected fuel cell operating on natural gas. The fuel cell in this configuration will provide electricity year-round, and thermal energy on a as needed basis. This will help reduce the emissions with use of grid power and natural gas heaters. Furthermore, the fuel cell will disconnect itself from the electrical grid in case of electrical outage, and continue to provide electrical power and thermal energy for critical loads – thereby providing a source of uninterrupted power supply.

An important part of this project is the fact that the Houston Zoo has free access to its utilities (including natural gas and grid electricity) – which makes a much more economical scenario for fuel cell installation.

Fuel Cell Description

The technology under consideration is a 5 kW natural gas fueled polymer electrolyte membrane (PEM) fuel cell from Plug Power (http://www.plugpower.com). The system is commercially sold under the name GenSys, and is available for purchase from the manufacturer. At least one other manufacturer, Nuvera, has a similar configured product, and is sold under the brand name of Avanti. The fuel cell is designed for residential and small commercial applications. The system produces 120/240 VAC @ 60 Hz and can be connected to the electrical utility grid. The system can be installed for combined heat and power (CHP) capability and is intended to supply base-loaded electrical power and thermal energy. The system can be set to able to follow the load up to 5 kW maximum power rating. The CHP capability allows thermal energy produces by the fuel cell system to be used in the existing domestic hot water and space heating systems.

Equipment specifications from Plug Power and real world demonstrations suggest that the system has an electrical efficiency in upwards of 25% (when new). Test data from several demonstrations also suggest that the unit degrades by about 20% (5 percentage points) in about 8000 hours of operation. The system also produces 9 kWth of thermal energy. Recent claims

from Plug Power and test data suggest that the fuel cell stack has a durability of around 8000 hours, although a deviation of ± 2000 hours is common. The system is CSA, UL, and FCC Class B certified.

Installation

Codes, Standards, and Permits
The Plug Power GenSys fuel cell system complies with the following standards:

- ANSI Z21.83, Fuel Cell Power Plants
- UL 1741, Inverters, Converters and Controllers for Use in Independent Power Systems
- NFPA 70, National Electrical Code
- Code of Federal Regulations 47, Part 15, Telecommunication Requirements
- IEEE P1547, Standard for Interconnected Distributed Resources with Electrical Power Systems
- New York State Standardized Interconnection Requirements
- California Energy Commission, Rule 21 Standard Interconnection Requirements

The implementation of distributed generation (DG) is subject to interconnection rules, building codes, electric generator codes, emissions standards and other regulatory requirements, which vary from state-to-state. Individuals or organizations accepting the installation are recommended to contact their local power utility company, local, and state regulatory authorities to discuss requirements in meeting the prevailing codes, regulations, and interconnection permits.

Typical Installation Considerations
Installation considerations when choosing a site are normally detailed in the manufacturer installation manual. Listed below are the excerpts, and some real world considerations:

- Site selection should be consistent with fuel cell technical specs, local building and fire codes. System must be placed in area of adequate ventilation and safety – four feet from walls, combustible/hazardous materials, etc.; and ten feet from walkways, trees, forced air building inlet, etc.; system must be accessible for vehicle access for installation and service and for emergency personnel. Bollards and security fencing may be required.
- Interconnection agreement with the local electric utility should be initiated four months prior to expected system delivery. Also contact should be made with state/city/county regulatory agencies to understand permit requirements and obtain necessary permits.

Typical Facilities Considerations
The fuel cell system is configured to run only with natural gas fuel. The fuel service should be established with the local gas company in advance of system delivery. The NG piping materials and joining methods should be consistent with the national and local codes and regulations. The gas supply system should be constructed to the following requirements:

- Gas supply pressure range is 4-11 inches WC. A step-down pressure regulator is needed if the gas pressure exceeds this range. The gas line and meter should be capable of supplying a maximum demand of up to 100 cubic feet per hour.
- A regulator (if needed), drip and sediment trap, manual shut off valve, and union disconnect should be installed no more than three feet from the point of connection on the fuel cell enclosure to allow for future service and repair of equipment.

- A plugged, 1/4 inch NPT connection point for test gauge connection should be installed immediately upstream of the fuel gas supply connection to the fuel cell system.
- The gas line must be purged completely of air before operating the fuel cell system (large amounts of air are harmful to the fuel processor).

A standard municipal supply water connection (maximum required flow 75 cc/min at 5 kW) is required. The on-board water purification system generates DI water (3 and 18 MΩ) for use in the process. A five liter on-board water reservoir is integrated within the fuel cell system

System Features
Important aspects of the installation of the GenSys® fuel cell system include:

- The GenSys® fuel cell system is an outdoor, stationary fuel cell powered electric generator designed foremost to provide supplemental AC electric power in parallel with the utility grid.
- The system primary application is for connection to electrical grids at 120 VAC, 60 Hz. The main operating state is Grid Parallel. The system provides 5 kVA (there is a customer option for 4 kVA at 100 VAC/50 Hz).
- The fuel cell system also has customer option for Standby mode, capable of providing power to selected loads during a loss of electrical grid.
- When fuel cell system is running, the Inverter automatically sends output power to the main service panel (grid) and critical load panel (standby). If standby loads are greater than fuel cell system output, the grid supplements the standby loads. If the standby loads are less than fuel cell system output, excess power is routed to the grid.
- If grid voltage is lost while the fuel cell system is running, the inverter disconnects from the grid and the fuel cell powers the critical load panel.
- If the fuel cell system shuts down automatically, the inverter powers the critical load panel from the grid.
- When the fuel cell system is shutdown for maintenance, the inverter can be aligned to use the grid to power the critical load panel. If inverter maintenance is required, an alternate means for powering the critical load panel must be provided or the critical load panel will be de-energized during that maintenance.

ENVIRONMENTAL OVERVIEW

Equipment:	*PlugPower GenSys™*
Time period of operation:	*1 year (continuous)*
Average power:	*5 kW*
Total electrical energy produced in one year:	*5 kW × 365 days/year × 24 hrs/day = 43,800 kWh = 43.8 MWh*
Total thermal energy produced in one year:	*9 kW × 365 days/year × 24 hrs/day × 0.75 (usage factor) = 59,130 kWh = 59.13 MWh*

Fuel:	*Natural Gas (delivered through pipeline – free of charge for Houston Zoo)*
Total Nat. Gas consumed:	*743 MCF (one year of operation)*

NOx savings

NOx emissions from fuel cell (~1.36 g NOx/MWh)	<< 1 kg NOx/year
NOx emissions with use of grid power (0.5 kg NOx/MWh)	21.9 kg NOx/year
NOx emissions from NG heater (0.23 kg NOx/MWh)	13.6 kg NOx/year
Net NOx savings with use of fuel cell	***35.5 kg NOx/year***

CO2 savings

CO2 emissions from fuel cell (743 MCF NG)	41 tons CO2/year
CO2 emissions from use of grid power (1.34 lbs CO2/kWh)	27 tons CO2/year
CO2 emissions from NG heater	15 tons CO2/year
Net CO2 savings with use of fuel cell	***1 ton CO2/year***

COST OVERVIEW

Equipment:	*PlugPower GenSys™*
Time period of operation:	*1 year (continuous)*
Average power:	*5 kW*
Total electrical energy produced in one year:	*5 kW × 365 days/year × 24 hrs/day = 43,800 kWh = 43.8 MWh*
Total thermal energy produced in one year:	*9 kW × 365 days/year × 24 hrs/day × 0.75 (usage factor) = 59,130 kWh = 59.13 MWh*
Fuel:	*Natural Gas (delivered through pipeline – free of charge for Houston Zoo)*
Total Nat. Gas consumed:	*743 MCF (one year of operation)*

Capital Costs

Equipment (GenSys 5 kW)	$42,000
Shipping	$2,000
Installation	$9,500
Grid-interconnection	$2,000
Subtotal1	***$56,000***

O&M Costs

Maintenance costs[1]	$4,500
Natural gas costs (*free for Houston Zoo*)	$0
Subtotal2	***$4,500***
Total	**$60,500**

[1] Includes one stack change

COST BENEFIT ANALYSIS FROM HOST PERSPECTIVE

Fuel Cell expenses	
Fuel Cell expenses for electricity and heat	$0
Fuel Cell expenses for maintenance	$4,500
Subtotal1	***$4,500***
Natural Gas and diesel backup generator expenses	
Natural gas heater maintenance	$1,500
Diesel backup generator maintenance	$1,000
Subtotal2	***$2,500***
Net savings = Subtotal2 – Subtotal1	
Fuel Cell net savings[2]:	**($2,000)**

[2] Trends over last few years indicate that fuel cell stack and systems costs are decreasing. Consequently, net savings with fuel cells might be positive.

SEP PROPOSAL

TEMPLATE # 5
EPA FUEL CELL APPLICATION

APPLICATION TITLE:	**FUEL CELL BASED COMBINED HEAT AND POWER APPLICATION FOR CAR WASH, LAUNDRY, AND SIMILAR INSTITUTIONS**
Type of Facility:	*Commercial*
Purpose of fuel cell:	*Provide hot water and electricity in CHP application*
Institutions interested in this application:	*Car wash facility, laundry, and similar places*

APPLICATION OVERVIEW

Objective

The primary objective of this project is to reduce the toxic emissions related to the operation of hot water natural gas heaters in the EPA Region 6. This will be accomplished with the use of a grid-connected fuel cell operating on natural gas. The fuel cell in this configuration will be base loaded on the thermal heat and will provide hot water year-round for small commercial laundry facility. The fuel cell will also provide electricity as an added benefit. Furthermore, the fuel cell will disconnect itself from the electrical grid in case of electrical outage, and continue to provide electrical power and thermal energy for critical loads – thereby providing a source of uninterruptible power.

Fuel Cell Description

The technology under consideration is a 5 kW natural gas fueled polymer electrolyte membrane (PEM) fuel cell from Nuvera Fuel Cells, Inc. (www.nuvera.com). The system is commercially sold under the name Avanti™, and is available for purchase from the manufacturer. The system produces around 4.6 kW of AC electrical power and 6.9 kW of thermal energy, and can be connected to the electrical grid. Avanti™ is Nuvera's third generation distributed generation product optimized for heat extraction. The system is primarily intended to meet residential (water, space, desiccant humidification, swimming pools, etc.) and commercial (restaurants, laundries, car washers, etc.) heating needs, rather than being optimized for electricity production. In theory, electrical power produced by the system can be used for peak shedding or other high value purposes in a way that could yield substantial air quality benefits. Operation of the system at key times, but under low duty cycle, could help potential problems with limited stack life or durability by matching operating hours to electric system peak hours. In a case where hot water is not needed, excess heat can be rejected with an outside radiator.

Table 1 lists the product specifications for the Avanti™ System.

Table 1: Avanti™ Fuel Cell System Product Specifications.

System Performance	
AC Rated Nominal Power Output	4.6 kW
AC Power Output	2.3 or 4.6 kW
AC Generation Efficiency[1]	>30% HHV (>33% LHV)
AC Output Options	1) 400/230 VAC, 50Hz single phase 2) 200 VAC, 50/60Hz 3 wire connection 3) 208 VAC, 60 Hz single phase
CHP Available Thermal Energy	6.9 kW
CHP Delivery Temperature	65˚C
Coolant Type	Water- Propylene Glycol
CHP Inlet Temperature	5-50˚C
Total Efficiency (Electric and Thermal)	75%
Operation Type	Unattended, grid parallel
Operating Modes	1 Continuous 2 Daily start-stop 3 Warm
Startup Time (from 10ºC)	120 minutes cold start or 30 minutes warm start.
Exhaust Emissions	Less than 10 ppm CO, NOx or unburnt Hydrocarbon
Routine Maintenance Interval	500 hr
Warranty	One year
Code Compliance	CE, CSA, UL
Mechanical and Environmental	
Operating Temperature	-20˚C to 40˚C[2]
Dimensions	W :120cm, D: 56 cm, H :140cm Volume : 941 liters
Weight	400 kg
Noise	70 dBA @ 1 m
Location	Indoor / Outdoor
Operating Altitude	-61 to 915m without de-rating and up to 1500m with lower efficiency.
Enclosure	Weatherproof
External Power	Grid Connection
Fuel and Water Requirements	
Fuel	Natural gas
Fuel Consumption at STP	15.33 kW HHV at maximum output
Fuel Supply Pressure	5 to 30 mbar
Required Water Quality	City Water
Water Balance	Negative to be drained

[1] HHV basis, 20ºC ambient, sea level, includes all parasitic losses at time of shipment.
[2] Operation at reduced power allowed above 35ºC.

Installation

Codes, Standards, and Permits
The Nuvera's Avanti™ system is CE, CSA, and UL listed. The implementation of distributed generation is subjected to interconnection rules, building codes, electric generator codes, emissions standards and other regulatory requirements, which vary from state-to-state. Individuals or organizations taking the installation are recommended to contact their local power utility company, local and state regulatory authorities to discuss requirements needed to meet the prevailing codes, regulations, and interconnection permits.

Typical Installation Considerations
Installation considerations when choosing a site are normally detailed in the manufacturer's installation manual. Listed below are the excerpts, and some real world considerations:

- Site selection should be consistent with fuel cell technical specs, local building and fire codes. System must be placed in areas of adequate ventilation and safety – four feet from walls, combustible/hazardous materials, etc.; and ten feet from walkways, trees, forced air building inlet, etc.; system must be accessible for vehicle access for installation and service, and for emergency personnel. Bollards and security fencing may be required.
- Interconnection agreements with the local electric utility should be started four months prior to expected system delivery. Also contact should be made with state/city/county regulatory agencies to understand permit requirements and obtain necessary permits.

Typical Facilities Considerations
The fuel cell system is configured to run only with natural gas fuel. The fuel service should be established with the local gas company in advance of system delivery. The NG piping materials and joining methods should be consistent with the national and local codes and regulations. The gas supply system should be constructed to the following requirements:

- Gas supply pressure range is 5-30 mbar. A step-down pressure regulator is needed if the gas pressure exceeds this range. The gas line and meter should be capable of supplying a maximum demand of up to 15.33 kW (HHV) at maximum output.
- A regulator (if needed), drip and sediment trap, manual shut off valve, and union disconnect should be installed no more than three feet from the point of connection on the fuel cell enclosure to allow for future service and repair of equipment.
- A plugged, 1/4 inch NPT connection point for test gauge connection should be installed immediately upstream of the fuel gas supply connection to the fuel cell system.
- The gas line must be purged completely of air before operating the fuel cell system (large amounts of air are harmful to the fuel processor).

Salient Features
Important aspects of the Nuvera Avanti™ system include:

- <u>High Efficiency</u> – At greater than 30% HHV AC efficiency and greater than 75% CHP efficiency, Avanti is one of the most efficient polymer electrolyte membrane fuel cell system in the world. Such high efficiency is in response to market requirements and is accomplished via system design and fuel cell stack architecture.

- Ability to Operate on City Water – Avanti™ can operate on city water and therefore obviates the need for expensive high purity water.
- Remote Monitoring and Control – To reduce the cost of operation and maintenance, the system comes with remote monitoring and control ability via Spy™ software
- Industrial Design – Based on Nuvera's global field demonstration experience, Avanti has the following features for easy installation and repair in the field
    a. Fuel processor can be removed in five minutes due to sliding plate mount
    b. Lift-off panels provide easy access to fuel and water filters
    c. Weather resistant enclosure with freeze protection heater provides ability to operate from -20 ^{o}C to 40 ^{o}C.

ENVIRONMENTAL OVERVIEW

Equipment:	*Nuvera Avanti™*
Time period of operation:	*1 year (16 hours per day) = 5840 hours*
Average thermal power:	*6.9 kW*
Average electrical power:	*4.6 kW*
Total thermal energy Produced in one year:	*6.9 kW × 365 days/year × 16 hrs/day = 40,296 kWh = 40.3 MWh*
Total electrical energy produced in one year:	*4.6 kW × 365 days/year × 16 hrs/day = 26,864 kWh = 26.9 MW*
Fuel:	*Natural Gas (delivered through pipeline)*
Total Nat. Gas consumed[3]:	*294.9 MCF (one year of operation @ 16 hours per day)*

NOx savings

NOx emissions from fuel cell (~1.36 g NOx/MWh)	<< 1 kg NOx/year
NOx emissions with use of grid power (0.5 kg NOx/MWh)	13.5 kg NOx/year
NOx emissions from NG heater (0.23 kg NOx/MWh)	9.3 kg NOx/year
Net NOx savings with use of fuel cell	***22.8 kg NOx/year***

CO2 savings

CO2 emissions from fuel cell (294.9 MCF NG)	16.3 tons CO2/year
CO2 emissions from use of grid power (1.34 lbs CO2/kWh)	12.2 tons CO2/year
CO2 emissions from NG heater	9.7 tons CO2/year
Net CO2 savings with use of fuel cell	***5.6 tons CO2/year***

COST OVERVIEW

Equipment:	*Nuvera Avanti™*
Time period of operation:	*1 year (16 hours per day) = 5840 hours*
Average thermal power:	*6.9 kW*
Average electrical power:	*4.6 kW*

[3] Natural Gas consumption of the Avanti™ fuel cell system is 50.49 scf/hr at full load.

Total thermal energy Produced in one year:	*6.9 kW × 365 days/year × 16 hrs/day = 40,296 kWh = 40.3 MWh*
Total electrical energy produced in one year:	*4.6 kW × 365 days/year × 16 hrs/day = 26,864 kWh = 26.9 MW*
Fuel:	*Natural Gas (delivered through pipeline)*
Total Nat. Gas consumed[4]:	*294.9 MCF (one year of operation @ 16 hours per day)*

Capital Costs	
Equipment (Avanti™)	$115,000
Shipping	$2,000
Installation	$12,000
Grid-interconnection	$2,000
Subtotal1	***$131,000***
O&M Costs	
Maintenance costs[5]	$4,500
Natural gas costs (*294.9 MCF at $8 per MCF*)	$2,359
Subtotal2	***$6,859***
Total	**$137,859**

COST BENEFIT ANALYSIS FROM HOST PERSPECTIVE

Fuel Cell expenses	
Fuel Cell expenses for electricity and heat (natural gas cost)	$2,359
Fuel Cell expenses for maintenance	$4,500
Subtotal1	***$6,859***
Current expenses (traditional system)	
Cost of grid electricity (26.9 MW @$0.10/kWh)	$2,690
Cost of thermal energy ($8/MMBTU; 75% eff.)	$1,483
Natural gas heater maintenance	$1,500
Subtotal2	***$5,673***

Net savings = Subtotal2 – Subtotal1

Fuel Cell net savings[6]: ($1,186)

[4] Natural Gas consumption of the Avanti™ fuel cell system is 50.49 scf/hr at full load.
[5] Includes one stack change
[6] Trends over last few years indicate that fuel cell stack and systems costs are decreasing. Consequently, net savings with fuel cells might be positive.

SEP PROPOSAL

TEMPLATE # 6
EPA FUEL CELL APPLICATION

APPLICATION TITLE:	**FUEL CELL BASED EMERGENCY BACK-UP POWER FOR POLICE STATIONS, FIRE STATIONS, RADIO STATIONS, AND SIMILAR INSTITUTIONS**
Type of Facility:	*Institutional*
Purpose of fuel cell:	*Provide backup power for battery charging during grid power outage.*
Institutions interested in this application:	*Police stations, Fire stations, radio stations, and similar places*

APPLICATION OVERVIEW

Objective

The primary objective of this project is to reduce the toxic emissions and provide a highly reliable backup power generator for emergency applications. These applications can include: charging batteries in hand-held radio sets at police stations, or supporting critical loads (like data servers) at police stations, fire stations or radio stations. This will be achieved by application of a fuel cell backup power generator operating on pure hydrogen. Operation of the fuel cell system at key times, but under low duty cycle, could help address potential problems with limited stack life or durability.

Fuel Cell Description

The technology under consideration is a 10 kW hydrogen fueled polymer electrolyte membrane (PEM) fuel cell from American Power Conversion Corporation (APC) (www.apc.com). The system is commercially sold under the brand name of APC InfraStruXure™, and is available for purchase from the manufacturer under standard terms and condition. The cost of the unit is around $29,000 ($2,900 per kW), but may vary from customer to customer based on contract. At least four other manufacturers, ReliOn, PlugPower, UTC, and Ballard have similar configured product, although these are available in different power ratings.

The APC InfraStruXure™ system operates on compressed, high-purity hydrogen gas. The system provides 192 V DC output needed by telecommunication, and data rooms/datacenters applications. The system has received CE and UL certifications.

The APC InfraStruXure™ system utilizes a 10 kW PEM fuel cell stack from Hydrogenics (www.hydrogenics.com). The system is built around the Hydrogenics proprietary H2X™ Series stack technology. Hydrogenics states that the power densities of current stacks offer high performance over 55% (LHV, for power output greater than 1 kW). The 10 kW module reached a net peak power of 14 kW at 350 A without exhibiting signs of performance loss. Hydrogenics

also claims that the system architecture of HyPM™ module provides performance unaffected by the start/stop cycling. Table 1 provides specifications for the APC InfraStruXure™ system.

Installation

Codes and Standards
The APC InfraStruXure™ is CE and UL certified. Following is a list of standards which must be referenced while installing the system:

- CGA 5.4, Standard for Hydrogen Piping Systems at Consumer Locations
- CGA 5.5, Hydrogen Vent Systems
- NFPA 50A, Standard for Gaseous Hydrogen Systems at Consumer Sites, 1999 – Hydrogen gas supply system must be designed, constructed and sited in accordance with the requirements of this standard
- NFPA 70 National Electrical Code
- NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Plants, 2000 Edition
- ANSI Z21.83, Fuel Cell Power Plant
- ICC International Fire Code – Table 2209, 3.1 Outdoor minimum separation distances for gaseous hydrogen dispensers, compressors, generators and storage vessels
- ICC International Fuel Gas Code – Chapter 7 – Gaseous hydrogen systems
- NFPA 497 – Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas

Typical Installation Considerations
Installation considerations when selecting a site are normally detailed in the manufacturer's installation manual. Listed below are the excerpts, and some real world considerations:

- Site selection should be consistent with fuel cell technical specs, local building and fire codes. System must be placed in area of adequate ventilation and safety – four feet from walls, combustible/hazardous materials, etc.; and ten feet from walkways, trees, forced air building inlet, etc.; system must be accessible for vehicle access for installation and service, and for emergency personnel. Bollards and security fencing may be required.

ENVIRONMENTAL OVERVIEW

Equipment:	*APC InfraStruXure™*
Time period of operation:	*Five years, providing backup grid security; 1000 operational hours*
Average power:	*10 kW (electrical)*
Total electrical energy consumed in five years:	*10 MWh*
Fuel:	*Hydrogen (delivered in standard industry size T-bottles)*
Total Hydrogen consumed:	10×10^3 *kWh* $\times$ *0.075 kg/kWh = 750 kg (five years of operation)*

NOx savings (five year basis)

NOx emissions from fuel cell UPS Generator (12.3 g/kg of H2)	9.2 kg NOx
NOx emissions from diesel generator (17.1 kg/MWh)	171 kg NOx
Net NOx savings with use of fuel cell backup generator	***161.8 kg NOx***

CO2 savings (five year basis)

CO2 emissions from fuel cell UPS Generator (10.6 kg/kg of H2)	7.95 tons CO2
CO2 emissions from diesel generator (824 kg/MWh)	8.24 tons CO2
Net CO2 savings with use of fuel cell backup generator	***0.29 tons CO2***

Particulates savings (five year basis)

Particulates emissions from fuel cell UPS generator (2 g/kg of H2)	1.5 kg particulates
Particulate emissions from diesel generator (695 g/MWh)	7.0 kg particulates
Net particulates savings with use of fuel cell backup generator	***5.5 kg particulates***

COST OVERVIEW

Equipment:	*APC InfraStruXure™*
Time period of operation:	*Five years, providing backup grid security; 1000 operational hours*
Average power:	*10 kW (electrical)*
Total electrical energy consumed in five years:	*10 MWh*
Fuel:	*Hydrogen (delivered in standard industry size T-bottles)*
Total Hydrogen consumed:	10×10^3 *kWh* $\times$ *0.075 kg/kWh = 750 kg (five years of operation)*

Capital Costs

Equipment (InfraStruXure™)	$29,000
Shipping	$3,000
Installation	$4,000
Subtotal1	***$36,000***

O&M Costs

Maintenance costs	$2,500
Hydrogen costs ($7.5/kg)	$5,625
Subtotal2	***$8,125***
Total	**$44,125**

COST BENEFIT ANALYSIS FROM HOST PERSPECTIVE

Equipment:	*APC InfraStruXure™*
Time period of operation:	*Five years, providing backup grid security; 1000 operational hours*
Average power:	*10 kW (electrical)*
Total electrical energy consumed in five years:	*10 MWh*
Fuel:	*Hydrogen (delivered in standard industry size T-bottles)*
Total Hydrogen consumed:	*10×10^3 kWh × 0.075 kg/kWh = 750 kg (five years of operation)*

Fuel Cell powered UPS Generator	
Maintenance costs	$2,500
Cost of hydrogen fuel (@ $7.5/kg of H2)	$5,625
Subtotal1	***$8,125***
Diesel powered UPS Generator	
Maintenance	$6,000
Cost of diesel (@ $0.42/kWh)	$4,200
Subtotal2	***$10,200***

Net savings = Subtotal2 – Subtotal1

Fuel Cell net savings:	**$2,075**

SEP PROPOSAL

TEMPLATE # 7
EPA FUEL CELL APPLICATION

APPLICATION TITLE:	**FUEL CELL POWERED AIR TUGGERS FOR DEMONSTRATION AT AIRPORTS**
Type of Facility:	*Institutional Building*
Purpose of fuel cell:	*Provide motive power to bag tuggers at airports*
Institutions interested in this application:	*Bush Intercontinental Airport, Hobby Airport*

APPLICATION OVERVIEW

Objective

The main goal of this project is to reduce the cost, maintenance, and emissions related to the operation of battery powered bag tuggers at airport facilities in the EPA Region 6. This will be achieved by utilization of fuel cell powered bag tuggers fueled with hydrogen. Utilization of such tuggers also enables quiet and vibration free operation leading to improved ergonomics.

Fuel Cell Description

The technology under consideration is a 12 kW hydrogen fueled polymer electrolyte membrane (PEM) fuel cell from General Hydrogen (http://www.generalhydrogen.com). The system utilizing the fuel cell stack technology from Ballard Power Systems is commercially sold under the name Hydricity™ Pack, and is available for purchase from the manufacturer. At least four other manufacturers, Hydrogenics, Proton Motor, Toyota, and Nuvera have similar configured products and are in different stages of development. The General Hydrogen's Hydricity™ Pack is designed to replace lead acid batteries in industrial vehicles, making them run longer and faster than trucks with batteries. Furthermore, these fuel cell powered packs can be refueled in fraction of time, compared to charging of batteries. These benefits are expected to result in significant increase in productivity and paybacks on investment of less than 4 years.

Equipment specifications from General Hydrogen suggest that the system is capable of delivering 12.5 kW of continuous power, and 48 kW peak power in 10 second bursts. The system can be designed for 36 or 48 VDC output. The system is water resistant and is designed to be operated in temperature range from -20 ^{o}C to 40 ^{o}C. The size of the fuel cell module is 32" × 38.6" × 22.7" and weighs around 1100 kg. The company claims that increase in productivity with use of Hydricity™ system is the main advantage over battery systems (Table 1).

System Integration and Operation

Fuel Cell Powered Bag Tuggers

Hydricity™ fuel cell power pack is designed to replace the battery bank in the bag tuggers employed at airports or similar locations. Conversion of battery powered electric bag tuggers to fuel cell powered tuggers will thus need minimum resources in terms of efforts or cost. General Hydrogen states that their products are available commercially for demonstration and real-world projects.

Fueling Solutions

General Hydrogen has developed complete hydrogen fueling solutions for its Hydricity™ fuel cell power system. These include hydrogen fuel, storage, dispensers, and fueling data management systems. Table 2 details the specifications for the hydrogen fuel pack. These products become more economical only when the fleet size or bag tuggers (or similar vehicles) are large. Consequently, this proposed use will be based on the hydrogen delivered through trucks and stored on-site in compressed form. On-site hydrogen compression and storage infrastructure will be developed (if not already available) and will be a part of this proposal.

Table 1: Comparison of Hydricity™ fuel cell system and battery system

Hydricity™ system	Battery system
Run three times as long as batteries	Hold a limited charge
Refuel in three minutes or less, keeping equipment working	Recharge slowly
Stay in the vehicle	Cause vehicle and operator downtime when changing batteries
Produce constant voltage, so vehicles never slow down	Produce lower voltage as they discharge, so equipment doesn't start as quickly
Need little space for fueling and no space for storage	Take up valuable space for changing, charging, and maintenance.
Are completely clean and produce no harmful emissions	Cause environmental problems in battery rooms

Table 2: Hydrogen Fuel Pack H-42

capacity of 93 lb hydrogen gas @ 6,250 psi (42 kg @ 450 bar)	350 or 450 bar (5,000 or 6,250 psi) storage pressure
700 bar (10,000 psi)—available 2005 (capacity of 158 lb / 72 kg)	manual operation standard
automated operation with Model CH350A hydrogen dispenser	98 x 69 x 63" (2,500 x 1,750 x 1,600 mm) LWH
3,960 lb (1,800 kg) total weight	stainless steel construction

Operation and Safety

The operation of the bag tuggers should be performed by certified and trained personnel only. The system should be operated as per the instructions in the operational and maintenance manual accompanying the product. Precautions common to battery powered bag tuggers should be followed during operation and refueling.

ENVIRONMENTAL OVERVIEW

Equipment:	*General Hydrogen Hydricity™ bag tuggers*
Time period of operation:	*Ten hours per day for 365 days per year (5475 hours)*
Average power:	*12 kW*
Total electrical energy consumed in one year:	*10 hours × 365 days × 12 kW = 43.8 MWh*
Fuel:	*Hydrogen (delivered on-site by truck)*
Total Hydrogen consumed[1]:	2682 kg *(one year of operation)*

NOx savings

NOx emissions from fuel cell bag tuggers (12.3 g/kg of H2)	32.9 kg NOx/year
NOx emissions from battery powered bag tuggers[2] (1.1 lbs NOx/MWh)	21.8 kg NOx/year
Net NOx savings with use of fuel cell bag tuggers	***(11.1 kg NOx/year)***

CO2 savings

CO2 emissions from fuel cell bag tuggers (10.6 kg/kg of H2)	28.4 tons CO2/year
CO2 emissions from battery powered bag tuggers (1.34 lbs CO2/kWh)	26.6 tons CO2/year
Net CO2 savings with use of fuel cell bag tuggers	***(21.8 tons CO2/year)***

Particulates savings

Particulates emissions from fuel cell bag tuggers (2 g/kg of H2)	5.4 kg particulates/yr
Particulates emissions from battery powered bag tuggers (80 kg/GWh)	3.5 kg particulates/yr
Net particulates savings with use of fuel cell bag tuggers	***(1.9 kg particul./yr)***

COST OVERVIEW

Equipment:	*General Hydrogen Hydricity™ bag tuggers*
Time period of operation:	*Ten hours per day for 365 days per year (5475 hours)*
Average power:	*12 kW*
Total electrical energy consumed in one year:	*10 hours × 365 days × 12 kW = 43.8 MWh*
Fuel:	*Hydrogen (delivered on-site by truck)*
Total Hydrogen consumed:	2682 kg *(one year of operation)*

[1] System requires around 60 grams of Hydrogen to produce 1 kWh electrical energy.
[2] Emissions (NOx, CO2, and Particulates) are for the electrical grid that is used to charge the batteries

Capital Costs

Fuel cell cost (12 kW Hydricity™)	$60,000
Bag tuggers (with batteries)	$20,000
Fuel cell integration into electric bag tuggers	$2,000
On-site hydrogen compression and storage infrastructure	$4,000
Subtotal1	***$86,000***

O&M costs

Maintenance Costs	$500
Hydrogen Cost[3] ($7.5/kg)	$20,115
Subtotal2	***$20,615***

Total	**$106,615**

COST BENEFIT ANALYSIS FROM HOST PERSPECTIVE

Equipment:	*General Hydrogen Hydricity™ bag tuggers*
Time period of operation:	*Ten hours per day for 365 days per year (5475 hours)*
Average power:	*12 kW*
Total electrical energy consumed in one year:	*10 hours × 365 days × 12 kW = 43.8 MWh*
Fuel:	*Hydrogen (delivered on-site by truck)*
Total Hydrogen consumed:	2682 kg *(one year of operation)*

Fuel cell powered bag tuggers

Cost of hydrogen fuel (@ $7.5/kg of H2)	$20,115
Maintenance	$500
Subtotal1	***$20,615***

Battery powered bag tuggers

Cost of grid electricity[4] (@ $0.10/kWh)	$4,380
Maintenance	$1,200
Subtotal2	***$5,580***

NET savings over battery powered bag tuggers = *Subtotal2 – Subtotal1 = ($15,035/year)*

[3] Depends on region – can be between $5-10/kg. With on-site hydrogen generation this cost can be as low as $3/kg of hydrogen

[4] Assuming 90% charging efficiency

SEP PROPOSAL

TEMPLATE # 8
EPA FUEL CELL APPLICATION

APPLICATION TITLE:	**FUEL CELL BASED PORTABLE POWER GENERATOR FOR LANDSCAPING EQUIPMENTS**
Type of Facility:	*Private, Commercial*
Purpose of fuel cell:	*Provide power for landscaping equipment*
Institutions interested in this application:	*Individuals, landscaping companies and similar*

APPLICATION OVERVIEW

Objective

The primary objective of this project is to obtain air quality benefits in the EPA Region 6 by adoption of fuel cell based zero emission generators. This can achieved by replacing small gasoline and diesel generators used for powering landscaping equipments with fuel cell generators. The power from fuel cell based power generator can be utilized in multitude of landscaping equipments including lawn movers, leaf blowers, chain saw, etc.

Fuel Cell Description

The technology under consideration is a 1 kW polymer electrolyte membrane (PEM) fuel cell system that runs on a methanol and water mixture and provides zero emission electricity with no noise and vibration. With the use of methanol, the refueling is simple as no hydrogen storage or infrastructure is needed. The fully integrated system is available from IdaTech (www.idatech.com) under the brand name of FCS 1200™. The unit is capable of providing on-site power wherever and whenever needed, and meeting noise and emissions standards for sensitive locations. These operating characteristics of the FCS1200 unit make it a potential candidate for replacement of existing, traditional portable power generator sets.

The FCS 1200™ consists of IdaTech's onboard FPM 20™ fuel reformer. The processor uses methanol fuel from an onboard tank and ambient air to convert it into high purity hydrogen using metal membrane purification technology for use in fuel cell stack. The system generates 1 kW of continuous DC power. An option pure sine wave inverter converts the DC electricity into high quality AC power (if desired).

The system specifications for the IdaTech FCS 1200 are given below.

Table 1: Specification of FCS 1200™ unit

Fuel:	Methanol/De-Ionized water mix
Fuel Mix Consumption (@ 1 kW):	1.4 Liters/hr
Fuel Mix Consumption (idle):	0.2 Liters/hr

Fuel Capacity:	11.2 Liters
Sound Level:	<55 dB @ 1 meter
Dimensions (LxWxH):	74 × 69 × 64 cm; 29” × 27” × 25”
Weight (varies w/options):	77-84 kg; 170-185 lbs.
Operating Temperature:	3 to 30° C
Storage Temperature:	-20 to 50° C
Exhaust Temperature:	<50° C
Ventilation Requirement (indoor use):	70 liters/sec
<u>AC Model Specs</u>	
Continuous Output Power:	850 Watts (120 VAC or 240 VAC) True Sine Output
Peak Output Power (10 sec.):	2000 Watts
Voltage Output:	120 VAC, +/- 5%, 60 HZ +/- 0.1% or 240 VAC +/- 5%, 50 Hz +/- 0.1%
<u>DC Model Specs</u>	
Continuous Output Power:	1000 Watts (48 VDC nominal)
Peak Output Power (1 min.):	2000 Watts (48 VDC nominal)
Voltage Range:	44.0 - 56.0 VDC

Installation

The IdaTech FCS 1200™ system is intended to replace traditional gasoline and diesel powered generators of a similar capacity. Conventional generators are currently used for a wide range of applications including battery charging, road side lighting, water pumping, signage, and miscellaneous uses. The design of the FCS1200™ may facilitate the adoption of electric equipment in applications currently served by small gas engines, including leaf blowers, weed whackers, lawn mowers, and other assorted lawn, garden, and landscaping equipment. Figure 1 schematically explains how the IdaTech FCS1200 unit can be used for this equipment. Utilization of the IdaTech FCS 1200™ in this setting will require modifications on part of the system to provide ruggedness during unit handling. Ruggedizing the unit will require significant investment and consequently will not be a part of this proposal. For calculation purposes, it is assumed that the unit will be used as available from the manufacturer.

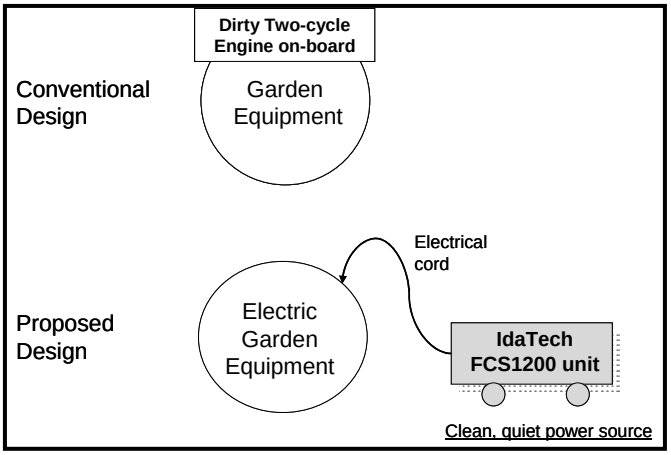

Figure 1: Schematic representation of use of IdaTech FCS 1200™.

ENVIRONMENTAL OVERVIEW

Equipment:	*IdaTech FCS 1200™*
Time period of operation:	*One year, providing portable power for landscaping equipments; 1000 operational hours*
Average power:	*1 kW (electrical)*
Total electrical energy consumed in five years:	*1 MWh*
Fuel:	*Methanol*
Total Methanol consumed[1]:	*1.4 liters/hour × 1000 hours = 1400 liters*

NOx savings

NOx emissions from fuel cell generator (<<1 kg/MWh)	<<1 kg NOx/year
NOx emissions from diesel generator (7.76 kg/MWh)	7.76 kg NOx/year
Net NOx savings with use of fuel cell generator	***7.76 kg NOx/year***

CO2 savings

CO2 emissions from fuel cell generator (1.09 kg/liter of methanol)	1526 kg CO2/year
CO2 emissions from diesel generator (824 kg/MWh)	824 kg CO2/year
Net CO2 savings with use of fuel cell generator	***(702 kg CO2/year)***

COST OVERVIEW

Equipment:	*IdaTech FCS 1200™*
Time period of operation:	*One year, providing portable power for landscaping equipments; 1000 operational hours*
Average power:	*1 kW (electrical)*
Total electrical energy consumed in five years:	*1 MWh*
Fuel:	*Methanol*
Total Methanol consumed:	*1.4 liters/hour × 1000 hours = 1400 liters*

Capital Costs

Equipment (FCS 1200™)	$22,500
Shipping	$2,000
Installation[2]	$3,500
Subtotal1	***$28,000***

O&M Costs

Maintenance costs	$1,500
Methanol cost[3] ($0.265/liter)	$371
Subtotal2	***$1,871***

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[1] Methanol consumption is 1.4 liters/hour at 1 kW (continuous power). When idles, the system consumes around 0.2 liters/hour. The system on-board methanol tank capacity is around 11 liters.
[2] Slight modification might be required to provide ruggedness
[3] Data taken from http://www.methanex.com/products/methanolprice.html (retrieved on July 2, 2006)

Total	**$29,871**

COST BENEFIT ANALYSIS FROM HOST PERSPECTIVE

Equipment:	*IdaTech FCS 1200™*
Time period of operation:	*One year, providing portable power for landscaping equipments; 1000 operational hours*
Average power:	*1 kW (electrical)*
Total electrical energy consumed in five years:	*1 MWh*
Fuel:	*Methanol*
Total Methanol consumed:	*1.4 liters/hour × 1000 hours = 1400 liters*

Fuel Cell powered Generator	
Maintenance costs	$1,500
Cost of methanol fuel (@ $0.265/liter of methanol)	$371
Subtotal1	***$1,871***
Diesel powered Generator	
Maintenance	$1,500
Cost of diesel (@ $0.42/kWh)	$420
Subtotal2	***$1,920***

Net savings = Subtotal2 – Subtotal1

Fuel Cell net savings:	**$49**

SEP PROPOSAL

TEMPLATE # 9
EPA FUEL CELL APPLICATION

APPLICATION TITLE:	**FUEL CELL BASED EMERGENCY BACK-UP POWER FOR 911 CALL PROCESSING CENTERS**
Type of Facility:	*Institutional*
Purpose of fuel cell:	*Provide backup power for data processing and call receiving at 911 centers during hurricanes.*
Institutions interested in this application:	*Police stations, Fire stations, and similar*

APPLICATION OVERVIEW

Objective

The primary goal of this project is to reduce the toxic emissions with use of portable diesel generators during grid power outage. The project also aims to provide a source of highly reliable backup power for calls and data processing at 911 centers during power outage (which is typical during hurricanes in the Gulf Coast region). This will be achieved by application of a fuel cell back up portable power generator operating on pure hydrogen. Operation of the fuel cell system at key times, but under low duty cycle, could help address potential problems with limited stack life or durability. Furthermore, use of fuel cell generators also enables quiet and noise free operation leading to improved ergonomics.

Fuel Cell Description

The technology under consideration is a 5 kW hydrogen fueled polymer electrolyte membrane (PEM) fuel cells from United Technologies Corporation (UTC) (www.utcfuelcells.com). The system is UTC's second generation product that incorporated the company's latest stack technology. The unit is sold under the brand name PureCell™ 5 and is available from the UTC under limited terms and conditions. The cost of the unit is around $15,000 ($3,000 per kW), but may vary from customer to customer based on contractual terms. Several other manufacturers including ReliOn, PlugPower, Ballard, APC, etc. have similar configured products, although these are available in different power ratings.

The UTC PureCell™ system operates on compressed, high-purity hydrogen gas. The system provides 48 VDC (nominal) in default setting and other voltage output options are available depending on the requirements. Table 1 lists preliminary specifications on the UTC PureCell™ 5 product (please note these are preliminary specifications and are subject to change).

Table 1: UTC PureCell™ 5 specifications.

Characteristic	Specification	Comments
Output power	5-kW net (maximum rated)	Capable of 0 to 5 kW
Total system efficiency	> 41% at max. power (5-kW net)	Higher at lower power outputs
Output voltage	48 VDC (nominal)	Other outputs can be made available
Grid loss	Provides instantaneous power	Includes batteries for seamless transition
Fuel type	Compressed H_2	"Industrial grade" H_2 is acceptable
Fuel consumption rate	~ 0.1 g/s of H_2 at 5 kW net	See chart on next page
Exhaust emissions	< 0.7% H_2 (vol.) and water vapor	< 1% H_2 is required by FC-1; No liquid water
Dimensions (h x w x d)	66.2 x 55.7 x 73.0 cm	21"-inches high in standard 19-inch rack
Operating temperature	2 to 35 C (power de-rate > 35 C)	Optional heaters available for < 2 C
Availability	Mid 2006	Partners for field trials being sought
Pricing	tbd	Highly dependent on volume and application

Installation

Codes and Standards

The UTC PureCell™ has not been certified to date. However, the company provides standard installation procedures that must be followed. Following is a list of standards which are generally referenced during system installation.

- CGA 5.4, Standard for Hydrogen Piping Systems at Consumer Locations
- CGA 5.5, Hydrogen Vent Systems
- NFPA 50A, Standard for Gaseous Hydrogen Systems at Consumer Sites, 1999 – Hydrogen gas supply system must be designed, constructed and sited in accordance with the requirements of this standard
- NFPA 70 National Electrical Code
- NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Plants, 2000 Edition
- ANSI Z21.83, Fuel Cell Power Plant
- ICC International Fire Code – Table 2209, 3.1 Outdoor minimum separation distances for gaseous hydrogen dispensers, compressors, generators and storage vessels
- ICC International Fuel Gas Code – Chapter 7 – Gaseous hydrogen systems
- NFPA 497 – Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas

Typical Installation Considerations

Installation considerations when choosing a site are normally detailed in the manufacturer installation manual. Listed below are the excerpts, and some real world considerations:

- Site selection should be consistent with fuel cell technical specs, local building and fire codes. System must be placed in area of adequate ventilation and safety – four feet from walls, combustible/hazardous materials, etc.; and ten feet from walkways, trees, forced air building inlet, etc.; system must be accessible for installation and service, and for emergency personnel. Bollards and security fencing may be required.

ENVIRONMENTAL OVERVIEW

Equipment:	*UTC PureCell™ 5*
Time period of operation:	*Five years, providing backup power for 911 center; 2000 operational hours*
Average power:	*5 kW (electrical)*
Total electrical energy consumed in five years:	*10 MWh*
Fuel:	*Hydrogen (delivered in standard industry size T-bottles)*
Total Hydrogen consumed[1]:	*2000 hours × 0.36 kg/hour = 720 kg (five years of operation)*

NOx savings (five year basis)

NOx emissions from fuel cell UPS Generator (12.3 g/kg of H2)	8.9 kg NOx
NOx emissions from diesel generator (17.1 kg/MWh)	171 kg NOx
Net NOx savings with use of fuel cell backup generator	***162.1 kg NOx***

CO2 savings

CO2 emissions from fuel cell UPS Generator (10.6 kg/kg of H2)	7.63 tons CO2
CO2 emissions from diesel generator (824 kg/MWh)	8.24 tons CO2
Net CO2 savings with use of fuel cell backup generator	***0.61tons CO2***

COST OVERVIEW

Equipment:	*UTC PureCell™ 5*
Time period of operation:	*Five years, providing backup power for 911 center; 2000 operational hours*
Average power:	*5 kW (electrical)*
Total electrical energy consumed in five years:	*10 MWh*
Fuel:	*Hydrogen (delivered in standard industry size T-bottles)*
Total Hydrogen consumed:	*2000 hours × 0.36 kg/hour = 720 kg (five years of operation)*

Capital Costs

Equipment (PureCell™ 5)	$15,000
Shipping	$2,000
Installation	$2,000
Subtotal1	***$19,000***

[1] UTC PureCell™ 5 System consumes around 0.36 kg hydrogen per hour of operation at 5 kW.

O&M Costs	
Maintenance costs	$2,500
Hydrogen costs[2] ($7.5/kg)	$5,400
Subtotal2	***$7,900***
Total	**$26,900**

COST BENEFIT ANALYSIS FROM HOST PERSPECTIVE

Equipment:	*UTC PureCell™ 5*
Time period of operation:	*Five years, providing backup power for 911 center; 2000 operational hours*
Average power:	*5 kW (electrical)*
Total electrical energy consumed in five years:	*10 MWh*
Fuel:	*Hydrogen (delivered in standard industry size T-bottles)*
Total Hydrogen consumed:	*2000 hours × 0.36 kg/hour = 720 kg (five years of operation)*

Fuel Cell powered UPS Generator	
Maintenance costs	$2,500
Cost of hydrogen fuel (@ $7.5/kg of H2)	$5,400
Subtotal1	***$7,900***
Diesel powered UPS Generator	
Maintenance	$4,000
Cost of diesel (@ $0.42/kWh)	$4,200
Subtotal2	***$8,200***

Net savings = Subtotal2 – Subtotal1

Fuel Cell net savings:	**$300**

[2] Depends on region – can be between $5-10/kg. With on-site hydrogen generation this cost can be as low as $3/kg of hydrogen

SEP PROPOSAL

TEMPLATE # 10
EPA FUEL CELL APPLICATION

APPLICATION TITLE:	**FUEL CELL AUXILIARY POWER UNIT FOR HEAVY-DUTY DIESEL TRUCKS**
Type of Facility:	*Materials Handling*
Purpose of fuel cell:	*Provide power for climate control and sleeper compartment on-board the heavy-duty trucks.*
Institutions interested in this application:	*Trucking Industry*

APPLICATION OVERVIEW

Objective

The primary goal of this project is to reduce the emissions during the idling of the line-haul trucks in the EPA Region 6. This can be achieved with use of fuel cell powered auxiliary powered unit (APU). The use of fuel cell powered APU will reduce the diesel emissions, noise pollution, as well as diesel fuel consumption. Operation of the fuel cell system at key times (during idling) but at under low duty cycle, could help address potential problems with limited stack life or durability.

Fuel Cell Description

Solid oxide fuel cells (SOFCs) typically serve the potential auxiliary power markets. At least one company Delphi, in collaboration with BMW, is developing SOFC systems for APU applications. Considering that this technology is still being developed and far from commercialization; and the fact that fuel cell APUs for trucks have large environmental and economic benefits, this proposal deals with the use of polymer electrolyte membrane (PEM) fuel cell technology (which is much more mature than SOFC) for APU applications.

PEM fuel cells are particularly attractive as truck APUs because they operate near ambient temperature, are easy to start and stop, and are prime candidates for cars and buses. However, these systems are intolerant to carbon monoxide and sulfur due to electro-catalyst poisoning. Consequently, these fuel cells operate on pure hydrogen streams, which in turn is derived from hydrocarbon based fuels (or other sources) off board the vehicle.

The technology under consideration is a 5 kW hydrogen fueled polymer electrolyte membrane (PEM) from Nuvera Fuel Cells (http://www.nuvera.com). The system is commercially sold under the name PowerFlow™, and is available for purchase from the manufacturer. At least three other manufacturers, Hydrogenics, Proton Motor, and Ballard have similar configured product are in different stages of development. The Nuvera Fuel Cell's system is designed to be installed into vehicles and equipment for a variety of applications, including material handling,

airport ground support, turf care, construction and standby power. The system is capable of producing regulated 36 or 48 VDC which is fully compatible with the battery systems. The system can be set to able to follow the load up to 5 kW maximum power rating.

Equipment specifications from Nuvera and real demonstrations suggest that the system has an electrical efficiency in upwards of 50% (when new). The company's product is available commercially, although it is still evolving. Nuvera states that their PowerFlow™ systems have been tested for over 9000 hours without appreciable drop in performance. Test data from an earlier generation fuel cell system (H2e™) suggests the electrical efficiency to be 53% (when new) and dropping to 46% after 1800 hours of continuous operation. The system is not certified, and the company states that CE, CSA, and UL listing are underway.

System Integration and Operation

A large proportion of heavy-duty trucks idle a significant amount of time (when they are not actively transporting a load). The power demanded during the truck idling is called the "hotel load" and is used to power climate control devices (for example: heaters and air conditioners) and sleeper compartment accessories (like refrigerators, microwave ovens, and televisions). The idle time can range from 6-16 hours per day. During this idle time, the diesel engine consumes around 1 gallon diesel fuel per hour reducing the amount of fuel for traction power. Idling engines operate very inefficiently – around 3% energy efficiency compared to 40% when operating on highway. Furthermore, these engines produce relatively high amount of NOx and particulate matter (although hydrocarbon and CO emissions are low) – which are two most air pollutant threats.

To reduce the idling time by large tractions motors, several alternative solutions have been proposed. The most common ones are: use of battery packs, auxiliary generators, direct-fired heaters, and thermal storage systems. All of these solutions have limited market acceptance. Fuel cells APUs have many advantages including potential low costs, increased driver comfort, and increased driver safety; and consequently is considered in this proposal.

The packaging and integration of APU is very important in terms of customer acceptability as well as safety and durability of the fuel cell system. Since no commercial-off-the-shelf system is available for APU application, this project involves some level of integration work to install a fuel cell and hydrogen storage system on-board the truck. Consideration should be given to placing major components as close together as possible to minimize transmission distance of high current electricity and hydrogen fuel. Although, the size of the fuel cell APU will dictate where the system can be integrated on the truck, the most obvious place is the frame rails of the truck (Line-haul trucks are quire large and there is usually some unused space along the frame rails). With advancement of fuel cell technology, these systems will become more compact providing alternative mounting locations in the trucks.

The operation of fuel cell powered APUs on line-haul trucks should be performed by trained drivers only. The system should be operated as per the instructions in the operational and maintenance manual accompanying the product. Precautions which are common to other APUs systems (like diesel powered generators, batteries, etc.) should be followed during operation and refueling.

ENVIRONMENTAL OVERVIEW

Equipment:	*Nuvera Fuel Cells PowerFlow™*
Time period of operation:	*Twelve hours per day, 365 days per year (4380 hours)*
Average power:	*5 kW*
Total electrical energy consumed in one year:	*4380 hours × 5 kW = 21.9 MWh*
Fuel:	*Hydrogen (on-board compressed hydrogen storage)*
Total Hydrogen consumed[1]:	1270 kg *(one year of operation)*

NOx savings

NOx emissions from fuel cell APU[2] (12.3 g/kg of H2)	15.6 kg NOx/year
NOx emissions from diesel APU (17.1 kg/MWh)	374.5 kg NOx/year
Net NOx savings with use of fuel cell forklift	***358.9 lbs NOx/year***

CO2 savings

CO2 emissions from fuel cell APU (10.6 kg/kg of H2)	13.5 tons CO2/year
CO2 emissions from diesel forklift (824 kg/MWh)	18.0 tons CO2/year
Net CO2 savings with use of fuel cell forklift	***4.5 tons CO2/year***

Particulates savings

Particulates emissions from fuel cell forklift (2 g/kg of H2)	2.5 kg particulates/yr
Particulate emissions from diesel forklift (695 g/MWh)	15.2 kg particulates/yr
Net particulates savings with use of fuel cell forklift	***12.7 kg particul./yr***

COST OVERVIEW

Equipment:	*Nuvera Fuel Cells PowerFlow™*
Time period of operation:	*Twelve hours per day, 365 days per year (4380 hours)*
Average power:	*5 kW*
Total electrical energy consumed in one year:	*4380 hours × 5 kW = 21.9 MWh*
Fuel:	*Hydrogen (on-board compressed hydrogen storage)*
Total Hydrogen consumed:	1270 kg *(one year of operation)*

Capital Costs

Fuel cell cost (5 kW PowerFlow™)	$18,000
Fuel cell integration into line-haul truck[3]	$5,000
On-site hydrogen compression and storage infrastructure	$4,000
Subtotal1	***$27,000***

O&M costs

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[1] Hydrogen flow is 60 slpm at 5.5 kW. System requires 58 grams of Hydrogen to produce 1 kWh electrical energy

[2] These (NOx, CO2, and Particulates) emissions are produced during hydrogen generation from steam reforming process in large central plants. So these refer to displaced emissions. Data taken from NREL report (NREL/TP-570-27637) "Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming."

[3] Cost estimate based on the survey of truck drivers done at UCD ITS

Maintenance Costs	$2,000
Hydrogen Cost[4] ($7.5/kg)	$9,527
Subtotal2	***$11,527***
Total	**$38,527**

COST BENEFIT ANALYSIS FROM HOST PERSPECTIVE

Equipment:	*Nuvera Fuel Cells PowerFlow™*
Time period of operation:	*Twelve hours per day, 365 days per year (4380 hours)*
Average power:	*5 kW*
Total electrical energy consumed in one year:	*4380 hours × 5 kW = 21.9 MWh*
Fuel:	*Hydrogen (on-board compressed hydrogen storage)*
Total Hydrogen consumed:	1270 kg *(one year of operation)*

Fuel cell powered APU

Cost of hydrogen fuel (@ $7.5/kg of H2)	$9,527
Maintenance	$500
Subtotal1	***$10,027***

Diesel powered APU

Cost of diesel (@ $0.42/kWh)	$9,198
Maintenance	$1,000
Subtotal2	***$10,198***

NET savings over diesel powered APU = *Subtotal2 – Subtotal1 = $171/year*

[4] Depends on region – can be between $5-10/kg. With on-site hydrogen generation this cost can be as low as $3/kg of hydrogen