

## **VII.G.6 An Advanced Buildings Proton Exchange Membrane (PEM) Fuel Cell System**

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### **Objectives**

- Demonstrate high electrical and overall efficiency, reduced energy consumption, and reduced emissions for hotel and follow-on applications
- Overcome technical and cost barriers through the engineering, design and construction of an integrated system utilizing fuel processor, advanced fuel cell, and balance of plant subsystems
- Validate a 50 kW proton exchange membrane (PEM) fuel cell system design through field testing at three separate facilities which have been co-selected by Marriott International, Portland State University, Semptra Utilities and Puget Sound Energy
- Use the information provided from this demonstration to target early market entry opportunities

### **Technical Barriers**

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells, and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- A. Durability
- B. Cost
- D. Thermal, Air and Water Management
- F. Fuel Cell Power System Integration
- G. Power Electronics
- H. Sensors
- I. Hydrogen Purification/Carbon Monoxide Cleanup
- J. Startup Time/Transient Operation

## Technical Targets

This project is focused on developing an integrated stationary PEM fuel cell power system that will meet or exceed the targets laid out in the project Functional Requirements Specification:

- Electrical energy efficiency @ rated power: 31%
- Combined heat and power energy efficiency @ rated power: 71%
- Durability @ <10% rated power degradation: 8,000 hours

## Approach

This project will achieve the program objectives by focusing on the following approach for the development of a high efficiency, low cost, high reliability 50 kW<sub>e</sub> PEM system:

- Combination of steam methane reformer and pressure swing adsorption (PSA) systems that are robust yet cost competitive
- Effective purification of natural gas and water sources that is long lasting and cost effective
- Use of industrial balance of plant (BOP) components with established reliability records
- Membrane electrode assemblies (MEAs) composition and operating conditions must be optimized for long life and acceptable power density.
  - Part of the development effort for this project is to identify and verify a set of conditions offering minimal voltage decay and fuel crossover from the anode to the cathode side caused by cell degradation.

## Accomplishments

- Designed, built, and tested a half-scale fuel processor system that produced over 400 sL/min (standard liters per minute) of product hydrogen and validated the following sub-system components:
  - PSA hydrogen purification
  - Natural gas compression and desulfurization
  - Water purification and pumping
  - Industrial burner and heat exchangers
- Operated single stacks and demonstrated that polarization curves fall within acceptable parameters for system target life when assembled into the multistack array.
- Located an off-the-shelf inverter solution that has been factory verified at >95% efficiency that will help the project to achieve the DOE efficiency targets.
- Performed the following:
  - Sub-scale furnace experiments to optimize reactor and catalyst geometry for the alpha reactor using a two factorial design-of-experiment
  - Alpha system heat balance using process simulation software for thermal efficiency optimization and heat exchanger design completed
  - Fluid dynamics pressure drop characterization of exhaust pathways using computational fluid dynamics (CFD) software
  - Developed a first principles mathematical model that correlated with the furnace experimental data that was then used for alpha reactor design. This model starts with the fundamental mass continuity, momentum and energy transfer equations and employs known reaction kinetic data and transport correlations to predict reactor performance and sizes

- Used past experiments and advanced modeling to develop the fully integrated alpha system (currently under construction)
  - Layout was designed using SolidWorks™ software to minimize tubing and electrical runs
  - System modules are arranged for maximum serviceability

### **Future Directions**

- Complete alpha system Safety review – August 2005
- Finish the construction of the fully integrated alpha system – September 2005
- Demonstrate full alpha system electrical output (50 kW<sub>e</sub>) – September/October 2005
- Alpha system preliminary design review – October 2005
- Complete alpha bill of materials – October 2005
- Future work will also include:
  - Beta system construction
  - Beta system factory acceptance tests
  - Beta field deployment for an 8,000 hour technology validation program

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### **Introduction**

The Advanced Buildings PEM Fuel Cell System project is focused on developing a fully integrated natural gas fired stationary power system capable of producing 50 kW of electric energy and 65 kW of thermal energy. This project has targeted hotels for technology validation and early market opportunities. Potential follow-on markets are: prison systems, hospitals, and commercial buildings. In order for this technology to become accepted on a larger scale multiple issues need to be examined and overcome. Some of the major issues are:

- System cost
- Durability/Lifetime
- Efficiency

These issues, and others, are being addressed by this project; success will help facilitate the acceptance of this technology on a broader scale. Work done on this project has focused on laying the groundwork for overcoming system obstacles. Extensive modeling and subscale testing was performed to develop a strong background for system design.

### **Approach**

The approach for the Advanced Building PEM Fuel Cell System project was to design with the DOE technical targets in mind. Extensive modeling and

subscale experimentation was conducted to develop an optimal reactor design. The reactor was designed for high thermal efficiency, durability and minimized cost. BOP components were selected from industrial applications that require long lifetimes and low parasitic losses. Multiple MEAs have been tested from different manufacturers to optimize lifetime while minimizing voltage decay and fuel crossover. Purification methods for the process fuel and water streams are designed for long lasting performance and cost competitiveness with a minimum service interval. An off-the-shelf DC to AC 50 kW<sub>e</sub> water cooled inverter has been selected to provide optimum conversion efficiency so that the heat losses can be captured into the system thermal recovery stream. Through collaboration with the inverter manufacturer the system fuel cells have been configured for optimum electrical efficiency. PSA has been chosen as the hydrogen purification method due to its proven industrial record and attractive cost potential as the appropriate scale for this project.

A proof of concept system was constructed and tested. Results from the testing were used to design an alpha system that is currently under construction. The alpha system will be tested and evaluated for six months before the beta systems are sited in the field. The initial beta proving sites will be two hotels and a college dormitory but follow-on markets could potentially include any commercial building with the appropriate electrical and thermal loads.

## **Results**

Over the past year, a half-scale engineering proof of concept fuel processor system has been designed and tested. Operation of that system allowed for the validation of many of the sub-system components such as the natural gas desulfurizer and compressor, water purification and pumping, industrial burner, and PSA hydrogen purification system. The overall product hydrogen output of the system was in excess of 400 sL/min. The recovery of product hydrogen from the reactor reformat stream by the PSA system was 80%. That system was highly instrumented and valuable data was collected through various experiments. Analysis of the data led to the conclusion that a simpler steam-reforming reactor design was possible.

Based on what was learned from the half-scale proof of concept system, a new reactor concept was developed and a designed set of sub-scale experiments were performed using an electric tube furnace and a single tube for the reactor vessel. The experiments were focused on optimizing the equilibrium hydrogen concentration in the reactor reformat stream. Other variables that were optimized through extensive testing were the overall reactor radial geometry and the industrial catalyst geometry. The furnace and reactor tube were highly instrumented to gather in-depth temperature profile data that was used to design the next generation alpha reactor. Along with the furnace experiments, a first principles mathematical model was developed and validated against experimental data. This validated model was then used to help design and size the alpha reactor. The alpha reactor design consists of a single tube reactor as apposed to its predecessor, the proof of concept reactor, which was a multi-tube array.

The extensive modeling, design work, and experimental tests have resulted in a design for the fully integrated alpha fuel cell system. This system is currently under construction and was designed using SolidWorks™ software to minimize the system footprint and for simplicity of maintenance. The alpha system incorporates the PSA design that was validated through the half-scale engineering proof of concept system. The high hydrogen recovery of the PSA system will help to achieve the system

efficiencies that are called out in the project Functional Requirements Specification (FRS) document that was submitted during the 2004 reporting period. The efficiencies in the FRS are directly derived from the DOE fuel cell technical targets.

The alpha system includes the fuel cell module that is made up of multiple single-stack sub-modules based on IdaTech's proven fuel cell platform. The single stack sub-models are designed with self contained BOP. This redundancy will allow for continued system operation even if one of the sub-modules requires service. All of the fuel cell stacks in the alpha system fuel cell module have been characterized and validated at the target power density. Each stack demonstrates over 20% capacity beyond the required power output for extended lifetime and durability. An off-the-shelf inverter will be used in the alpha system to convert the unregulated DC power into 3 phase 208 VAC. This inverter has been factory tested and provides electrical conversion efficiencies in excess of 95%. This high efficiency inverter will significantly support the DOE efficiency targets.

The fully integrated alpha fuel cell system is under construction and will be going through initial testing and shakedown during September and October of 2005.

## **Conclusions**

- Thermal integration for optimized heat transfer in the steam reformer is essential for high fuel processor efficiency. Heat transfer through radiation is fundamental for optimized thermal efficiency in the steam reformer.
- Fuel cell sub-modules (single stack) with individual balance of plant components will provide a level of redundancy for a more reliable fuel cell system.
- Sub-scale testing and mathematical reactor modeling have proven to be very valuable in shortening the system development time.
- The preliminary PSA design that was validated in the engineering proof of concept system had sufficient performance to move directly into the alpha system without re-sizing.

- This fully integrated alpha fuel cell system is under construction and will be going through initial testing and shake-down at the end of this summer.

**FY 2005 Publications/Presentations**

1. Annual DOE Hydrogen Review presentations 2004 and 2005