V.I.1 Development and Demonstration of a New-Generation High Efficiency 1-10 kW Stationary Fuel Cell System

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Objectives

The objectives of this project are to identify and seek out methods to facilitate overcoming specific challenges related to the development of fuel cell technologies and their deployment for commercial use in combined heat and power (CHP) applications.

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 are:

(A) Durability
(B) Cost
(C) Performance

Technical Targets

This project is developing novel fuel processing, polymer electrolyte membrane (PEM) fuel cell technologies and integration strategies in order to help achieve DOE targets for integrated stationary PEM fuel cell power systems for year 2011. These targets are:

- Electrical energy efficiency @ rated power – 40%
- CHP energy efficiency @ rated power – 80%
- Cost – $750/kW (in volume production)
- Durability – 40,000 hours lifetime

Forecasted project progress toward meeting DOE targets is shown in Table 1.

TABLE 1. Progress Toward DOE Targets

Target[1]	2009[2]	2010	2011	2012[3]
Electrical Efficiency @ Rated Power	30-35	35-37	37-38	>38
CHP Energy Efficiency @ Rated Power	70	75	80	>85
Cost ($/kW)	$400/kW			
Durability (hours)	1,000	2,000	5,000	>10,000

[1] Table values are projections based on modeling work done by IE
[2] To be validated experimentally in September 2009
[3] Depends largely on successful development and system integration of adsorption-enhanced reforming

Accomplishments

- Extended run (513 hours) of small scale reformer that consistently yielded ~65% thermal efficiency while undergoing 53 thermal cycles.
- Completed the design of a TRL 4 (component and/or breadboard validation in a laboratory environment) fully integrated CHP system using IE's PEM fuel cell and hydrogen generation technology platforms.
- Developed a novel coating for IE's bi-polar fuel cell plate, improved diffuser materials and catalyst optimization that in combination have boosted stack efficiency by 3% more than levels achieved in 2008.
- >1,000 hours fuel cell system run time demonstrated in lab trials.

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Introduction

The development of highly efficient and cost-effective clean energy solutions is not without challenge. The maturation of hydrogen fuel cell technologies is expected to become a significant player in reducing our dependence on imported fossil fuels and help curb the creation of greenhouse gases.

This project is directed at designing a stationary CHP system using a PEM-based hydrogen fuel cell that will provide residential and light commercial end-users with on-site generated electrical and heating needs. The proposed technology approach combines a chemical reactor (reformer) and purifier that convert either a liquid or gaseous hydrocarbon feedstock such as natural gas, into hydrogen that is then fed into the fuel cell where a reaction between hydrogen and oxygen produces electrical power in a non-combustion reaction. This reaction in turn generates an electric current and heat is recovered from this exothermic process. The parallel focus on adsorption enhanced reforming (simultaneous reforming and removal of CO_2) may lead to the enabling technology that promises greater efficiencies and lower capital costs than conventional reforming.

Approach

The approach used to develop the new-generation 1-10 kWe CHP unit that achieves high efficiency, long durability and low cost targets simultaneously includes a bold optimization and integration of existing IE technology platforms. The CHP unit will be based on IE's open architecture integration philosophy that maintains a high purity hydrogen interface between the hydrogen generation and fuel cell subsystems. The fuel cell subsystem will be derived from IE's existing 2 kW CHP platform and its advanced 10 kW evaporatively-cooled fuel cell that achieves 60% gross efficiency on pure hydrogen. An innovative hydrogen generation subsystem will be developed by leveraging IE's Phase 1 experience into a newly redesigned 10 kWe steam reformer (SR) and integrated fast cycle pressure swing adsorption (PSA) off-gas purifier. This hydrogen generation platform currently achieves thermal efficiencies in the ~63-68% range. In parallel, IE has been investigating an adsorption-enhanced reformer (AER), that when modeled using simulation software, suggest possible efficiencies of 75-80%.

The approach depends on achieving an optimized balance between increased stack performance (high cell voltage at high current densities), low cost cell components, hydrogen generation efficiency (high fuel conversion, lower steam/carbon ratios, maximum recuperation of heat and water vapor, and high hydrogen recovery), low parasitic power components, efficient grid-connected inverter and lowest cost balance of plant.

Results

Accomplishments to date include the following:

Fuel Processor Development

After completing the design and build of a new SR, the vessel was tested both with and without being integrated into the PSA. The high pressure core reactor was then examined after completing 513 hours of hot operation and deemed to have maintained (by visual inspection) its mechanical integrity. Being that the reformer was subjected to several thermal cycles without serious damage, this suggests that the basic design may indeed be a good candidate for further ruggedization with the potential to be long-lived (see Figure 1).

Data collected during the reformer testing shows that repeatable efficiencies of ~65% were achieved.

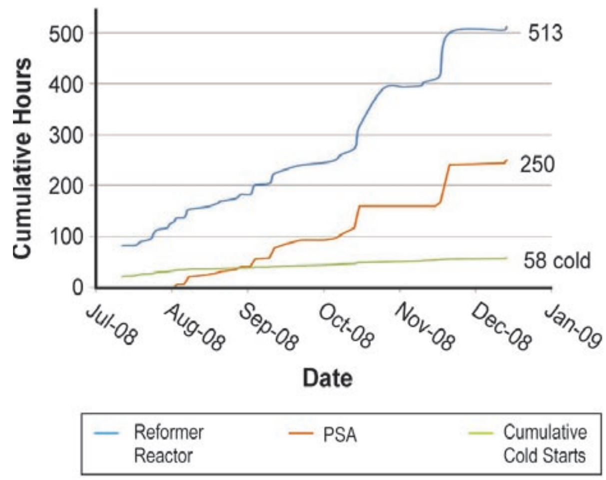

FIGURE 1. Hydrogen Generator Testing

TABLE 2. Hydrogen Generator Experimental Efficiencies

Date and Time	Feed CH_4 (SLPM)	Supplemental CH_4 (SLPM)	Total CH_4 (SLPM)	Produced H_2 (SLPM)	Efficiency LHV (%)
9/24/2008 16:27	69.5	0	69.5	151	65.2
9/24/2008 17:29	69.4	0	69.4	150	64.9
9/30/2008 17:11	69.8	5.3	75.1	164	65.5
10/1/2008 11:20	69.5	5.3	74.8	163	65.7
10/1/2008 13:30	70	0	70	153	65.9
10/1/2008 15:00	61	4.6	65.6	142	65.2
10/22/2008 11:04	70	5	75	162	65.1
10/22/2008 16:00	60.7	6	66.7	145	65.3
10/22/2008 17:40	62	7	69	150	65.3

LHV - lower heating value

Table 2 shows these results from tests during the months from September to October 2008.

AER

The work on adsorption enhanced reforming is continuing at California Polytechnic University Pomona (CPP) under the direction of professors Dr. Winny Dong and Dr. Vilupanur Ravi. A four-tube AER reactor has been designed and constructed in preparation of testing during July-August 2009. The rig is configured to produce hydrogen continuously. These tests will be conducted using liquid ethanol as the feed. Simulation models conducted previously by Sandia National Laboratories suggest that if the AER system engineering proves successful, a CHP system fuel-to-electric efficiency may approach 48%. Feasibility data using a potassium-promoted hydrotalcite adsorbent with the AER approach were submitted in report last year's Fiscal Year 2008 annual report. Figure 2 shows the new test rig at CPP. The heated reactor tubes are within a furnace in the center of the photograph with the gas delivery and programmable logic controller equipment on the left side.

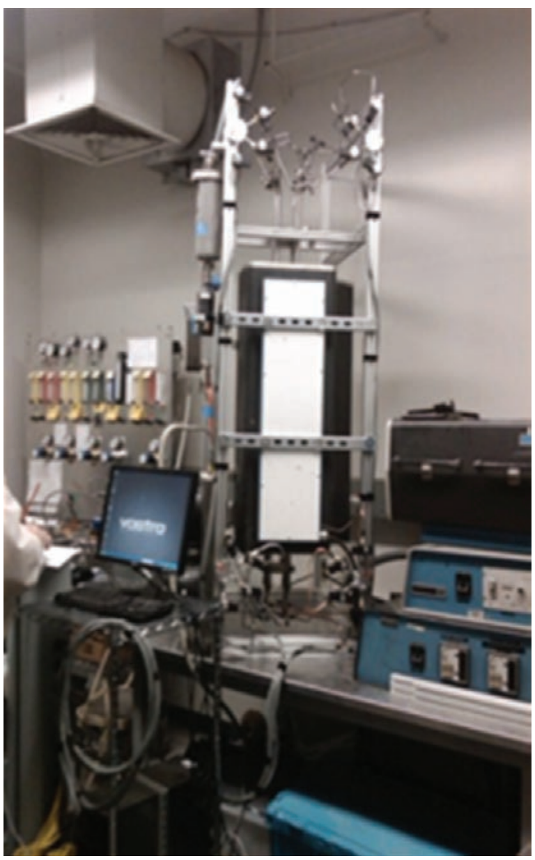

FIGURE 2. AER Test Rig

Fuel Cell

Continued improvements including the use of new diffuser materials, catalyst optimization and the use of novel bipolar coating materials resulted in an increase from 0.56 to 0.7 V @ 0.5 A/cm^2 thus resulting in a 2-3% uplift of efficiency over results obtained in 2008.

CHP

During FY 2009, a fully integrated CHP system has been designed. Based on heat and materials balances, a complete set of engineering documents have been created including process flow diagrams, piping and instrumentation diagrams, bills of materials and mechanical models for the entire system and its 23 related subsystems. Construction of this CHP prototype is underway and substantial progress has been made. The system will be using a Matlab/Simulink automated controller which has been coded for remote monitoring of system performance with controlled safety related shutdowns and alarm sequences. Shakedown testing is scheduled for September 2009. Figure 3 shows a high level prototype CHP system under development.

Conclusions and Future Directions

FY 2009 has culminated with significant progress with regard to the integrated design of both the fuel cell and reforming technology platforms into a CHP system. Validation testing will begin in September and provide

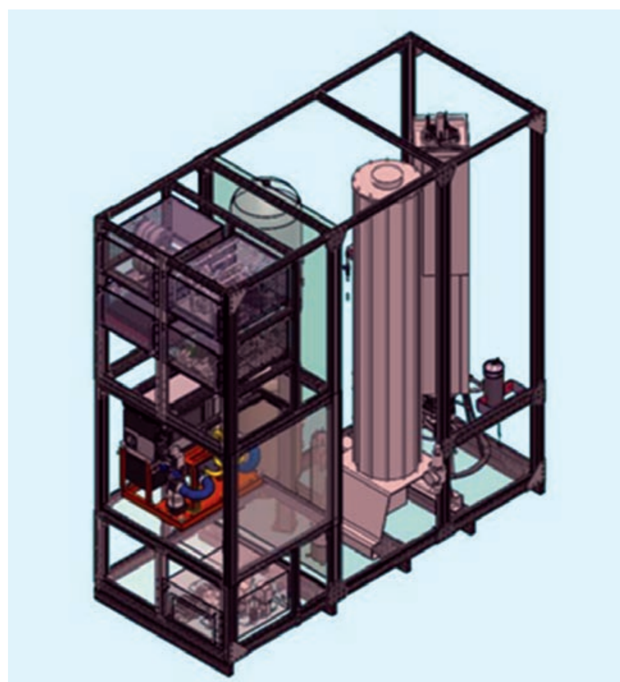

FIGURE 3. CHP Prototype Mechanical Drawing

valuable data for consideration into a field-deployable system that will go through the cost engineering marking process. Afterwards, the unit will be installed and commissioned within a European Union nation during 2010. In order to work toward higher efficiencies, FY 2010 will bring additional focus on developing the AER technology and optimization of balance-of-plant components. Major tasks/direction going forward include:

- Engage potential system packaging/manufacturing partners.
- Complete deployable system design verification documentation.
- Evaluate alternate PSA technologies.
- Design/build rotary valve to enable system integration/testing of AER.
- Install and field-commission a 10 kWe CHP system.

Special Recognitions & Awards/Patents Issued

1. Woods, Richard R.; Porter, Brooks F.; Durai-Swamy, K.; October 21st, 2008, United States Patent # 7439273, "Hydrogen Purification Process and System"

FY 2009 Publications/Presentations

1. 2009 DOE Annual Merit Review-Washington, DC, May 20th, 2009. Presentation FC 25.

2. 2009 ASME 7th International Fuel Cell Science, Engineering & Technology Conference-Newport Beach, CA, July 7th, 2009. "Low-Cost, High Efficiency Distributed Hydrogen Production for CHP".

3. Li, Mingheng, Equilibrium Calculation of Gaseous Reactive systems with Simultaneous Species Adsorption, Journal of Industrial and Engineering Chemistry, Res. 2008, 47, 9263-9271.

References

1. Development of 50 kW Fuel Processor for Stationary Fuel Cell Applications, Stevens, et al., Chevron, 2007, Final Report, DE-FC36-03GO13102.

2. Sircar, et al., I&EC Res., 46, 5003-5014 (2007)] and one in press [J. Hydrogen Energy, 33 (2008)].

3. Sircar, S., Kratz, W.C.: Simultaneous production of hydrogen and carbon dioxide from steam reformer off-gas by pressure swing adsorption. Sep. Sci. Technol. 23, 2397–2415 (1988).

4. Sircar, S., Hufton, J.R., Nataraj, S.: Process and apparatus for the production of hydrogen by steam reforming of hydrocarbon. U.S. Patent No 6,103,143 (2000).