V.I.7 Low-Cost Co-Production of Hydrogen and Electricity*

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Contract Number: DE-FC36-0515195

Subcontractors:
- University of Alaska, Fairbanks, AK
- Udelhoven Oilfield System Services, Anchorage, AK

Vendors:
- H2 Pump LLC, Latham, NY
- Giner Electrochemical Systems LLC, Newton, MA

Project Start Date: November 13, 2006
Project End Date: December 31, 2009

*Congressionally directed project

Objectives

- Demonstrate efficient, reliable and durable solid oxide fuel cells for stationary applications.
- Demonstrate co-production of electricity and hydrogen.
- Determine the feasibility of a delivered cost of hydrogen below $2.50 per gge by 2010.

Technical Barriers

From the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan, specific technical barriers addressed by this project are:

Section 3.4: Fuel Cells

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

Section 3.6: Technology Validation

(I) Hydrogen and Electricity Co-Production

Technical Targets

TABLE 1. Progress towards Meeting Technical Targets for Low-Cost Co-Production of Hydrogen and Electricity

Characteristic	Target	Current Status
PSOFC Performance (System efficiency)	>45% PSOFC system efficiency η = (AC power exported to grid) /(LHV natural gas)	Achieved >45% PSOFC system efficiency on both systems in Alaska; 51.1% peak system efficiency
PSOFC Performance (Peak grid-tied power)	25 kW grid-tied fueled by natural gas	>25 kW grid-tied demonstrated on both systems in Alaska; 25.9 kW peak
PSOFC Performance (Durability)	Operate system for 1 year in the field	Both systems operating since December 3, 2008; each has >5,000 h runtime with >97% availability at >15 kW grid-tied (as of June 30, 2009)
Hydrogen Purity	Sufficient purity to power a PEM fuel cell	Demonstrated hydrogen purity with undetectable levels of CO and CO_2 (<1 ppm) and -70°C dewpoint using enhanced hydrogen pump
Hydrogen Production	19 kg/day peak hydrogen production by purifying PSOFC anode exhaust	Full-scale hydrogen pump purified simulated PSOFC exhaust at flow rates up to 19.3 kg/day; Integration testing with PSOFC system has commenced
Distributed production of hydrogen from natural gas	2010 Target: $2.50/gge (delivered)	DOE H2A model estimates $4.53/gge without taking any credit for electricity produced; Estimate drops to $0.97/gge with $0.12/kWh credit for electricity

PSOFC – planar solid oxide fuel cell; AC – alternating current; LHV – lower heating value; PEM – proton exchange membrane; gge – gasoline gallon equivalent

Accomplishments

- Demonstrated rated power of 25 kW grid-tied for both PSOFC systems in Alaska fueled by natural gas using standard Bloom Energy hot boxes.
  - Project was planned for field demonstration of a single 25 kW system.

- All balance-of-plant components have been validated on two operational systems in Alaska; each has >5,000 h runtime with >97% availability at >15 kW grid-tied, as of June 30, 2009.
- Demonstrated 51.1% PSOFC peak system efficiency (η).
  - η = (AC power exported to grid)/(LHV natural gas).
- System remotely monitored 24-7 by team of trained operators.
- Full-scale hydrogen pump purified simulated PSOFC exhaust at flow rates up to 19.3 kg/day.
  - Integration testing with PSOFC system has commenced.
- DOE H2A model used to estimate cost of co-producing hydrogen at below $2.50/gge when taking credit for value of electricity produced.
  - Estimate drops below $1/gge with $0.12/kWh credit for electricity.

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Introduction

Bloom Energy's fuel cell systems, when manufactured in high volume, can produce low-cost hydrogen by co-producing hydrogen and electricity simultaneously with one common set of low-cost equipment. The main objectives of this project are to 1) deliver and field test a fuel cell electricity generator in Alaska; 2) demonstrate hydrogen production from a hydrogen pump in a lab-based fuel cell system similar to that to be operated in Alaska; and 3) analyze the feasibility of a delivered cost of hydrogen below $2.50 per gge.

Approach

The project is divided into two phases. Phase 1 includes the build of a PSOFC electricity generator; the design, permitting and build of a demonstration site; and the installation, commissioning and start up of the generator. This phase also includes evaluation of several hydrogen production technologies for integration and validation with a lab-based PSOFC.

Phase 2 covers the one-year demonstration of the PSOFC electricity generator. It also includes the build, test and demonstration of the hydrogen generation sub-system. The delivered cost of hydrogen, using the DOE H2A model, is also included in Phase 2. More specifically, the following is included:

- Test a vendor-provided hydrogen pump prototype in stand alone mode (completed).
- Analyze the volume and purity of hydrogen produced by prototype unit (completed).
- Design the integration of the vendor-provided hydrogen pump production unit with our PSOFC system (completed).
- In our lab, test the hydrogen pump integrated with our PSOFC system (in process).
- Analyze the volume and purity of hydrogen produced (in process).
- Operate the PSOFC system in the field for 12 months (in process).
- Analyze the efficiency and availability of the fuel cell (in process).
- Analyze the results of PSOFC electricity and hydrogen co-production (pending).

Results

Phase 1 of the project is complete. Phase 2 is in process. The PSOFC demonstration began in November 2008 and demonstration readiness of the H2 Pump hydrogen production system began in 2008.

Fuel Cell Demonstration

The fuel cell demonstration site in Anchorage, Alaska was designed and permitted in the first quarter of 2008. Construction completion and operational permitting occurred in October 2008. Two 25 kW PSOFC modules were installed, commissioned and started up in November 2008. Approval to grid connect was received on December 1, 2008. The one-year demonstration started on December 3, 2008. System demonstration objectives are projected as follows:

- 25 kW peak grid-tied power
- Operation on natural gas
- Operate at 480 V
- Grid parallel operation
- Remote monitoring
- 70% uptime over one year demonstration
- 45% peak net electric efficiency in electric-only mode

As of June 30, 2009, system performance is listed in Tables 2 and 3.

TABLE 2. System 1C Performance Statistics December 3, 2008 – June 30, 2009

25 kW Operation	System 1C	
Average AC Efficiency	44	%
Peak AC Efficiency	51.1	%
Total Energy Output	100,182	kWhrs
Total Fuel Consumption	22,771,244	L
Peak AC Power	25.9	kW
Hrs On-Site	5,023	hrs
Uptime	5,002	hrs
Load Hrs	4,895	hrs
Availability at 15.0 kW+	97.3	%
Grid Faults	9	
System Faults	10	

TABLE 3. System 1D Performance Statistics December 3, 2008 – June 30, 2009

25 kW Operation	System 1D	
Average AC Efficiency	45	%
Peak AC Efficiency	49.1	%
Total Energy Output	103,267	kWhrs
Total Fuel Consumption	22,902,074	L
Peak AC Power	25.4	kW
Hrs On-Site	5,023	hrs
Uptime	5,010	hrs
Load Hrs	4,897	hrs
Availability at 15.0 kW+	97.5	%
Grid Faults	7	
System Faults	4	

Hydrogen Production Demonstration

A hydrogen pump from H2 Pump, LLC of Latham, New York was chosen as the demonstration vehicle for the hydrogen production portion of the project. A small-scale H2 Pump product was validated at Bloom Energy's laboratories and demonstrated that hydrogen pumping: 1) is scalable, 2) has high electrochemical efficiency (low power required/kg H_2), 3) is a continuous flow device having a near infinite turn down ratio with minimal parasitics when not pumping hydrogen, and 4) can pump hydrogen on demand. A 120-cell H2 Pump was procured and the design for integration to a 25 kW PSOFC was completed.

Hydrogen production will be demonstrated in the next reporting period. Objectives are as follows:

- Two operational modes
  - Hydrogen recycle
  - External hydrogen delivery
- SOFC operation at 95% fuel utilization in recycle mode
- 2,000 hours test duration, with <5% performance degradation of hydrogen production.

In addition to the hydrogen pump, a partial pressure swing adsorption (PPSA) prototype was specified and contracted for development. Delivery is expected in September 2009. It is expected that the PPSA will be operated as follows:

- No water-gas shift required
- Low parasitic electrical power
- Anode exhaust to be separated
  - Flow rate: 99 slpm
  - Temperature: 30°C
  - Supply pressure: 5 inches water column
  - H_2 (29.3%), CO_2 (66%), H_2O (3.4%) and CO (1.3%)
- PPSA effectiveness
  - 80% fuel recovery (CO, CH_4, H_2)
  - 95% CO_2 separation

Hydrogen Cost Analysis

The DOE H2A cost model was used to estimate the cost of co-producing hydrogen from a distributed PSOFC system without taking credit for the value of electricity produced. For the assumptions stated in the Current Analysis (H2A Model) shown in the right column of Table 4, the DOE H2A model estimates the delivered cost of hydrogen to be $4.53/gge without taking any credit for the value of electricity produced. This is very close to the $4.82/gge estimated by scaling the modeling performed at Bloom Energy (BE) when this project was proposed in 2005 to a 200 kW output and increasing the capacity factor from 90% to 98%.

By taking credit for the value of electricity produced, the estimated delivered cost of hydrogen drops considerably and can be below $1/gge. Using the DOE H2A model and assuming $0.12/kWh for the value of electricity, the delivered cost of hydrogen is $0.97/gge, as shown in Table 5.

TABLE 4. Hydrogen Cost Analysis Using the DOE H2A Model

H_2 Cost Analysis Using DOE H2A Model		
	Original Proposal (BE model)	**Current Analysis (H2A Model)**
Installed Capital Cost	$1,500/kW	$1,500/kW
Overall **System** Efficiency	56%	56%
Overall **Electrical** Efficiency	33%	33%
Natural Gas Cost	$8/mmBtu	AEO 2007
Capacity Factor	90%	98%
H_2/Year	50,192 kg	54,656 kg
Electrical Output	200 kW	200 kW
Delivered cost of H_2/gge	**$4.82**	**$4.53**

BE & H2A models are very consistent; differences are in assumed capacity factor

TABLE 5. Hydrogen Cost Analysis Adding the Value of Electricity

H_2 Cost Analysis Adding Value of Electricity		
	Original Proposal (BE model)	**Current Analysis (H2A Model)**
Delivered cost of H_2/gge	$4.82	$4.53
Value of Electricity	$0.12/kWh	$0.12/kWh
Electrical output	1,576,800 kWh/year	1,716,960 kWh/year
Value of annual output	($167,360)	($182,240)
H_2/Year	50,192 kg	54,656 kg
Value of Electricity/kg H_2	($3.77)	($3.77)
H_2 cost, net/gge @ 300 psi	**$1.26**	**$0.97**

Projections are consistent with DOE delivered cost of H_2 goals

Conclusions and Future Directions

Next steps in this project include the following:

- Complete PSOFC system demonstration in Anchorage, Alaska.
- Complete H2 Pump demonstration.
- Validate PPSA design.

FY 2009 Publications/Presentations

1. A presentation was made at the DOE Hydrogen Program Annual Merit Review held in Crystal City, Virginia in May 2009.